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Environmental Assessment

Waste Treatment Facility

OWMC
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Waste Management
Corporation

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[redacted]

OWMC TREATMENT FACILITY
PROCESS AREA REPORT
INCINERATION

Prepared by
Monenco Limited
One St. Paul St.
St. Catharines, Ontario

November 1986

MONENCO LIMITED

ONE ST. PAUL STREET, ST. CATHARINES, ONTARIO
CORRESPONDENCE:
P.O. Box 1540, St. Catharines, Ontario L2R 7J9
Tel: (416) 688-9263
Telex: 061-5219
Cables: "Monenco"

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Ontario Waste Management Corporation
2 Bloor Street West
11th Floor
Toronto, Ontario
M4W 3E2

Attention: Mr.R. V. Griffiths
Project Manager

Gentlemen,

OWMC Treatment Facility
Monenco Contract No.: MNC 8084-2

Process Area Report
Incineration

We are pleased to submit herewith the draft report entitled: Process Area Report - Incineration. The report describes the rationale for the selection of technologies including the conceptual design of the incineration plant of OWMC's proposed Facility for the treatment and disposal of liquid industrial and hazardous waste in Ontario.

We trust that this report meets the Corporation's requirements.

Yours very truly,

J. V. Fitzgerald
Project Manager

RM/jj

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EXECUTIVE SUMMARY

PURPOSE OF THE REPORT

This report describes the rationale for the selection of technologies included in the conceptual design of the incineration plant of OWMC's proposed Facility for the treatment of liquid industrial wastes and hazardous wastes.

The background and rationale for including high temperature thermal destruction of organic wastes in the design of OWMC's Facility has been presented in earlier reports (Ref: The Proctor & Redfern Group[1], OWMC[2,3]). The choice of rotary kiln incineration, physical/chemical treatment, solidification and an engineered landfill as the four major components of the Facility was subsequently confirmed by A. D. Little of Canada Limited in their report entitled "Rationale for the Selection of Technologies for the Treatment and Disposal of Special Wastes in Ontario" - July 1985 (Ref: A. D. Little[4]).

Therefore, this report focuses on the alternative technologies which can be included in the rotary kiln incineration system for the cooling and treatment of flue gases resulting from the combustion process, prior to the cleaned gases being discharged to atmosphere. The report describes the alternative technologies considered, the methodology used to compare and evaluate them and the results of technology selection. The report also describes how the selected technologies have been combined into a rotary kiln incineration system and outlines how the complete system has been optimized to maximize the performance, safety, flexibility and reliability of the incineration operation.

This process area report on the incineration plant is one of five such reports which together cover all areas of OWMC's proposed treatment Facility. These reports provide additional technical backup data and information in support of the system design and operating description presented in the Facility Description report (Ref: Monenco Limited[5]). Process area reports for Physical/Chemical Treatment, Solidification, Engineered Landfill and General Facilities are contained in separate documents (Refs: Monenco Limited[6,7,8,9]).

This report was prepared for OWMC by Monenco Limited, who are also responsible for preliminary engineering of the overall treatment Facility. A substantial amount of technical input to this report was provided by OWMC's Incineration Technology Consultants, namely:

- Environmental Elements Corporation, Baltimore, Maryland, U.S.A.
- Von Roll Limited, Zurich, Switzerland
- Hessische Industriemüll GmbH (HIM), Wiesbaden, West Germany

The rationale for technology selection was prepared by Monenco Limited and confirmed by OWMC's Incineration Technology Consultants, whereas the system optimization is primarily the result of work undertaken by the Technology Consultants.

It is important to appreciate from the outset, the contribution which the rotary kiln incineration system will make as part of a treatment philosophy, in ensuring that OWMC's Facility can treat Ontario's special wastes in a safe manner which will minimize risk to human health and impact on the environment. This is explained below:

- Organic wastes which are delivered to OWMC's Facility in various physical forms for treatment and disposal, will be destroyed by high temperature thermal oxidation using a rotary kiln incineration system.

- The incineration system will include provisions for cooling the gaseous products of combustion (flue gases) and for treating the cooled flue gases to remove contaminants, prior to the cleaned gases being discharged to atmosphere via a stack.

- The physical/chemical treatment plant is designed to treat aqueous organic wastes which contain low concentrations of organic contaminants. Organic contaminants which are recovered from these aqueous wastes will be incinerated together with aqueous wastes containing low concentrations of organics directly, should these wastes not be amenable to treatment by physical/chemical processes.

- Inorganic residues from the incineration plant will be disposed of in an engineered landfill, together with residues from the physical/chemical processes, after they have been solidified to produce a material which is both physically and chemically stable.

The incineration plant provides the capability of destroying any organic contaminants delivered to the Facility, whether they be in solid or liquid, pumpable or non-pumpable form, whether they be in concentrated raw wastes or bound in primarily inorganic residues arising from physical/chemical treatment processes, or even trace organic contaminants of concern remaining in the treated effluent following physical/chemical treatment, if so required. In short, the incineration plant provides the means to destroy any organic species which may be delivered to the Facility as may be determined in order to protect human health and the environment.

SCOPE AND METHOD

A systematic approach was used to evaluate and select the preferred combination of flue gas cooling and flue gas treatment technologies best suited for OWMC's incineration plant. The selected rotary kiln incineration system was optimized to ensure that OWMC's goals of minimizing risk to human health, impact in the environment and cost, are achieved in a satisfactory manner.

The following points summarize the methodology used to evaluate alternative technologies for the flue gas cooling and flue gas treatment components of the rotary kiln incineration system.

- Establish the major treatment objectives and key treatment philosophies for the proposed incineration plant.
- Establish criteria for technology selection.
- Establish a "short list" of potentially suitable technologies and alternatives to these technologies.
- Define specific treatment requirements for each stage of the rotary kiln incineration system and list alternative technologies which are potentially capable of meeting these objectives.
- Identify alternative incineration system designs incorporating the short-listed technologies.
- Evaluate and rank the relative suitability of each conceptual system design according to the established criteria and select the preferred system for inclusion in the conceptual process design.

PREMISES AND POSTULATES

OWMC has developed the following basic planning principles and guidelines which are central to technology selection and process design in all areas of the proposed Facility including the incineration plant.

- Wastes must undergo treatment to the fullest extent possible using best available proven technology, prior to the safe disposal of the remaining treated residues.

- It is the Corporation's goals to:
  - minimize risk to human health,
  - minimize environmental impacts and
  - minimize financial costs to OWMC and the people of Ontario.

The following additional premises provided by OWMC have been used as starting points for technology selection and process design of the incineration plant.

- The incineration plant will be designed to treat special wastes which are primarily organic in nature. Wastes which are primarily inorganic in nature will be sent to the physical/chemical plant for treatment. Inorganic residues from the incineration plant will be further treated, as required, by physical/chemical treatment and/or solidification processes prior to them being disposed of in an engineered landfill. Incinerator slag will be disposed of directly in the engineered landfill unless it is shown that the leachability characteristics of this residue can be further improved by prior treatment.

- The incineration plant will be designed for an initial capacity of 30 000 t/a of organic special wastes based on a total Facility capacity of 150 000 t/a.

- o The initial incineration plant capacity will be achieved by the installation of a single rotary kiln incineration system.

- o The ultimate design capacity of the incineration plant will be 60 000 t/a, and this will be achieved by installing a second incineration system of 30 000 t/a capacity.

- o Space will be provided on the Facility for the installation of a second rotary kiln incineration system similar to that initially proposed.

- o The arrival of wastes at the Facility will be scheduled in advance.

- o The types and quantities of special wastes which could require treatment at the incineration plant have been derived from OWMC's Waste Profile information, produced in November 1984.

- o The waste profile shown in bold face on Table 1 (pg. 8) is typical of the types and quantities of waste the incineration plant could receive. However, variations may result from:

  - the effectiveness of OWMC's 4R program, which is to encourage industry in Ontario to reduce, recover, recycle and reuse industrial waste,
  - industry's response to market demands and to financial constraints,
  - process and manufacturing changes, and
  - changes in Provincial waste regulations.

On this basis it is important that the incineration plant design incorporate features such as:

- maximum flexibility,
- future expansion capability, and
- reserve storage and treatment capacity.

Postulates are assumptions or hypotheses which are basic to the approach used to evaluate alternatives and arrive at an optimum process design. The key assumptions, treatment objectives and treatment philosophies which have influenced technology evaluations and process design for the incineration plant are summarized below:

- o The incineration plant will be designed to achieve the following treatment objectives:

  - To treat incoming special waste of a primarily organic nature such as to provide a Destruction and Removal Efficiency (DRE) of not less than 99.99% for each Principal Organic Hazardous Constituent (POHC) designated in the waste feed, consistent with the requirements of the U.S. Environmental Protection Agency (Ref: EPA[44]). While most regulating authorities have set limits for the emission rate of organics to the atmosphere, the US Environmental Protection Agency is currently the only regulating authority that attempts to regulate incinerator performance by relating the organic emission from an incinerator to the organic feed rate of the incinerator (Destruction of Organics, Pg. 212). It was decided in the early stages of conceptual design to adopt this performance requirement for OWMC's Facility.

  - To treat flue gases from the combustion process so that contaminants such as particulates (dust), acid gases and inorganic metals are removed to the maximum extent possible using best available proven technology, prior to the flue gases being discharged to atmosphere. The flue gas quality must ensure that the resulting point of impingement contaminant concentrations at least meet the requirements of the Environmental Protection Act of Ontario, RSO 1980, Regulation 308 (Ref: MOE[12]), including any provisional regulations or guidelines.

- To produce residues which can be treated by physical/chemical processes, including solidification, prior to them being safely disposed of in an engineered landfill.

- To incinerate organic residues from the physical/chemical treatment plant to the same treatment objectives established for special wastes.

- To ensure that treatment objectives can be carried out safely.

o Aqueous organic wastes which are not amenable to physical/chemical treatment will be incinerated. Similarly, batches of inorganic waste which contain unacceptable concentrations of organics even after treatment, may also be incinerated. The incineration system will therefore be equipped to dispose of contaminated water.

o The physical form and method of delivery to the Facility of organic special waste has been estimated as follows, from OWMC's Waste data.

Waste Form	Method of Delivery	Tonnes/Annum (t/a)	Percentage of Organic Waste
Bulk Solids	Truck/Container	7 860	26.2
Solids and Sludges	Drums	10 200	34.0
Liquids	Drums	870	2.9
Liquids and Sludges	Tank Trucks	11 070	36.9
		30 000	100.0

The incineration system must therefore be designed to accommodate varying physical forms of waste including solids, sludges, and liquids, fed to the incineration process as bulk solids, in drums or via pumps. The rotary kiln incinerator provides this flexibility.

- Sizing of the incineration process components will be based on 7000 operating hours a year and a capacity factor of 90%. Hence, the design capacity of the initial incineration system is 4.76 t/h calculated as follows:

  $$\text{Design capacity} = \frac{(30\ 000)}{7000 \times 0.9} = 4.76 \text{ t/h}$$

- The maximum continuous heat input of the incineration system will be based on waste having an average lower heating value (LHV) of 14 000 kJ/kg, which has been estimated from OWMC's waste data. The unit will be capable of operating continuously at the resulting thermal capacity of 66.64 GJ/h.

- The incineration system must be capable of operating below its design capacity in recognition of the fact that quantities of organic waste delivered to the Facility will vary, and are expected to build up over a period of years. The system will therefore be designed to operate in a safe, efficient and reliable manner at any capacity from 50% to 100% of its rated thermal capacity.

- The incineration process will be designed to operate at temperatures of up to 1400°C and will normally operate above 1000°C in the rotary kiln and secondary combustion chamber prior to the introduction of secondary air. The temperature will be maintained above 1200°C when burning certain waste types, as further discussed in Chapter 4.

- The incineration system will be designed to accommodate the following variations in waste feed characteristics, based on an assessment of OWMC's waste data:
  - heating value variations from 11 000 kJ/kg to 42 000 kJ/kg without supplementary fuel firing. Below 11 000 kJ/kg supplementary fuel will be required.
  - water content varying up to 50% by weight of total waste feed.
  - inert solid content varying up to 30% by weight of total waste feed.

- The flue gas treatment system will be designed to remove particulate, heavy metals and acid gases from the flue gas produced when incinerating waste types envisioned for OWMC's Facility. The normal and maximum concentrations of chlorine and sulphur expected in the organic waste were estimated based on an assessment of OWMC's waste data, and knowledge of what similar installations were being designed for in both Europe and North America. The resultant design basis is as follows:

	% Weight	
	Normal Operation	Maximum
Chlorine	5	15
Sulphur	1	3

- The incineration plant will operate in a continuous mode, 24 hours a day, 7 days a week.

- Analytical tests will be conducted on samples of waste prior to incineration to determine important parameters such as heating value, chlorine, sulphur, water and inorganic content, and concentrations of critical components such as certain metals. This will permit the preparation of daily "menus" of waste to be incinerated and thereby ensure that the design limitations of the incineration system in the destruction and removal of specific chemicals, are not exceeded.

STATUS OF DATA

The waste profile developed by OWMC is considered to be typical, since the nature and quantities of various waste types which will be sent to OWMC's Facility for treatment will not be known until the Facility is in operation, and will continue to change throughout its operating life.

These factors have been taken into consideration in the selection of technologies and in the design and optimization of the incineration system.

Much of the data used in the evaluation of alternative technologies is based on information from current literature, operating facilities, and from technology vendors.

A logical and quantitive methodology was adopted to evaluate alternative flue gas cooling and treatment technologies. This methodology was adopted to assist in the technology selection process to enable all of the technology selection criteria to be accounted for in a rational manner during the evaluation process while at the same time ensuring that important selection criteria are properly accounted for. This methodology has not however eliminated the need for qualitative evaluation and engineering judgement in the selection of the preferred technologies, as further explained on pg. 31.

Optimization of the selected rotary kiln incineration system was conducted by the Incineration Technology Consultants, based on data available to them from a number of similar operating facilities, including the rotary kiln incineration plant at HIM, Biebesheim, West Germany, which is almost identical to the system proposed for OWMC's Facility.

The evaluation and prediction of expected performance of OWMC's incineration plant is similarly based on confirmed data from similar operating facilities.

MAIN FINDINGS

The rotary kiln incineration system which has been selected for OWMC's incineration plant consists of the following main components:

- o Combustion System:
  - rotary kiln incinerator, with
  - secondary combustion chamber.

- o Flue Gas Cooling System:
  - waste heat recovery boiler.

- o Flue Gas Treatment System:
  - spray dryer,
  - electrostatic precipitator,
  - three stage wet scrubber.

Optimization of this incineration system resulted in the following important design features:

- o Combustion System:

  - A rotary kiln incinerator operating in the high temperature "slagging" mode thereby achieving the best possible residue (slag) properties.
  - Rotary kiln and secondary combustion chamber liberally sized to provide ample flue gas residence time in the high temperature zone, varying from 3.1 - 3.5 seconds at temperatures ranging from 1100°C to 1400°C, thereby achieving the best possible destruction of organics. This does not preclude operation at a temperature of 1000°C, if required.
  - Secondary combustion chamber includes secondary air injection to ensure turbulent mixing of combustion air with combustion flue gases, also contributing to high combustion and destruction efficiencies.

- o Flue Gas Cooling System:

  - Two stage flue gas cooling using air injection in the first stage, to maintain a constant flue gas temperature at the inlet of the heat recovery boiler.

- A convective type heat recovery boiler having a mechanical tube cleaning system and a single, horizontal flue gas flow arrangement which has been proven in many installations to provide the highest achievable reliability and "on-line" availability i.e. maximum uninterrupted operating period each year.

o Flue Gas Treatment System:

- A system combining the performance attributes of a wet flue gas scrubber into an "effluent-free" process, while still permitting the recovery of useful energy, as steam, in the flue gas cooling stage.
- A spray dryer for the evaporation of scrubber effluent, having a rotary atomizer for the reliable introduction of effluent.
- A three field electrostatic precipitator having an efficiency of 99% and equipped with rigid electrodes or rigid frame discharge electrodes for the reliable removal of contaminants, in solid form, from the system.
- A three stage wet scrubber comprising a first stage quench followed by chevron mist eliminators, a second stage packed bed for the removal of hydrogen chloride followed by chevron mist eliminators, a third stage Ring Jet™ (see footnote 1) operated at 400 mm Water gauge (WG) pressure drop for the removal of sulphur dioxide and fine particulates including aerosols of heavy metals, and final mist eliminators comprising a combination chevron/mesh pad arranged in series.

The resultant design combines best available proven technology into a system design which maximizes the destruction of organic species and minimizes the discharge of residual contaminants to the environment. In this manner, the system achieves OWMC's primary goals of minimizing risk to human health and impact on the environment.

1. Ring Jet™ is a trademark of Ciba-Geigy, Ltd., Basel, Switzerland.

Optimization of the system design and operating philosophies have resulted in the following additional system features and characteristics.

- o Provision has been made to reconfirm the characteristics of waste prior to incineration, and to achieve controlled delivery of waste to the system by:
  - separate storage of different types of organic waste in the incinerator tank farm, organic drum handling building and bulk solid waste pits,
  - pre-blending of pumpable "waste batches" at the incinerator tank farm,
  - pre-scheduling the delivery of specific drums of waste to the incinerator from the drum handling building, and
  - mixing of dry solid wastes in a pit provided for this purpose at the incineration plant.

  These provisions also ensure that the feeding of waste to the incineration system is as uniform as practical, that sudden changes in the characteristics of waste being incinerated are minimized, and that the design capabilities of the system are not exceeded.

- o Maximum flexibility has been incorporated in the system design to accommodate variations in the specific types of waste to be incinerated.

- o Special provisions are proposed for the safe handling and disposal of custom waste such as that from hospitals, to the incineration system.

- o Special provisions are also provided for the storage, handling and incineration of segregated organic wastes such as those containing polychlorinated biphenyls (PCBs).

- o High heat content liquid wastes are used to automatically control the total incinerator heat release, thereby maintaining consistent, stable operation of the process system.

- Flexibility in system design is incorporated to operate the rotary kiln incinerator at temperatures ranging from 1000°C to 1400°C in the high temperature zone prior to the introduction of secondary air. The flue gas residence time at these temperatures will always be greater than 3 seconds at full load operation, and can be increased to over 5 seconds by operating at reduced incinerator load (70% full load).

- Flue gases will be reheated prior to them being discharged to atmosphere, since this results in improved dispersion of flue gases and a reduction in the visibility of the steam plume, during certain atmospheric conditions.

- A minimum stack height of 60 m is proposed, since the residual contaminant emissions from the system represent a small percentage of those permitted by Ontario Regulations (MOE[12]) and the additional cost and visual impact associated with a higher stack is not considered justified.

- Solidification of the dry flyash and salt from the flue gas treatment system will be conducted at the incineration plant, to avoid potential fugitive emissions of these materials which might result from their transportation to and rehandling at the solidification plant.

- Many safety features have been included in the system design to ensure that both human and environmental safety is achieved at all times. (Ref: Section 4.4.2, pg. 201).

It should be noted that work is presently being conducted by other OWMC consultants to address compliance of Facility emissions with Ontario regulations and to determine health risks resulting from such emissions. This work is ongoing and being undertaken by Ontario Research Foundation and Environ Corporation respectively, and will be available prior to the formal environmental assessment submission.

The results obtained to date from the work being conducted by Environ Corporation and Ontario Research Corporation indicate that OWMC's incineration plant will treat organic wastes in a highly effective manner which will thereby minimize risk to human health and impact on the environment.

CHAPTER 1
INTRODUCTION

1.1 PURPOSE OF THE REPORT

This report describes the rationale for the selection of technologies included in the conceptual design of the incineration plant of OWMC's proposed Facility for the treatment of liquid industrial wastes and hazardous wastes.

The background and rationale for including high temperature thermal destruction of organic wastes in the design of OWMC's Facility has been presented in earlier reports (Ref: The Proctor & Redfern Group[1], OWMC[2,3]). The choice of rotary kiln incineration, physical/chemical treatment, solidification and an engineered landfill as the four major components of the Facility was subsequently confirmed by A. D. Little of Canada Limited in their report entitled "Rationale for the Selection of Technologies for the Treatment and Disposal of Special Wastes in Ontario" - July 1985 (Proctor A. D. Little[4]).

Therefore, this report focuses on the alternative technologies which can be included in the rotary kiln incineration system for the cooling and treatment of flue gases resulting from the combustion process, prior to the cleaned gases being discharged to atmosphere. The report describes the alternative technologies considered, the methodology used to compare and evaluate them and the results of technology selection. The report also describes how the selected technologies have been combined into a rotary kiln incineration system and outlines how the complete system has been

optimized to maximize the performance, flexibility, reliability and safety of the incineration operation.

This process area report on the incineration plant is one of five such reports which together cover all areas of OWMC's proposed treatment Facility. These reports provide additional technical backup data and information in support of the system design and operating description presented in the Facility Description report (Ref: Monenco Limited[5]). Process area reports for Physical/Chemical Treatment, Solidification, Engineered Landfill and General Facilities are contained in separate Process Area Reports (Refs: Monenco Limited[6,7,8,9]).

Chapter 2 of the report summarizes the policies and objectives of OWMC, identifies the types of wastes that are expected to be treated in the incineration plant and the basic assumptions (premises and postulates) which have governed the technology evaluation and system design of the incineration plant. Chapter 3 then presents the results and conclusions of the technology evaluation process including reasons for either accepting or rejecting each alternative considered.

Chapter 4 of the report describes the manner in which the selected flue gas cooling and treatment systems have been incorporated into the overall rotary kiln incineration system for the destruction of organic waste at OWMC's proposed Facility. This chapter also outlines the manner in which the process design of the total system has been optimized and the resultant performance that can be expected.

This report was prepared for OWMC by Monenco Limited, who are also responsible for preliminary engineering of the overall treatment Facility. A substantial amount of technical input to this report was provided by OWMC's Incineration Technology Consultants, namely:

- Environmental Elements Corporation, Baltimore, Maryland, U.S.A.
- Von Roll Limited, Zurich, Switzerland
- Hessische Industriemüll GmbH (HIM), Wiesbaden, West Germany

The rationale for technology selection described in Chapters 2 and 3 of this report was prepared by Monenco Limited prior to the appointment of OWMC's Technology Consultants, who subsequently confirmed the selections.

The system optimization described in Chapter 4 is primarily the result of work undertaken by OWMC's Incineration Technology Consultants, with the exception of auxiliary system and layout studies conducted by Monenco Limited and stack plume dispersion studies conducted by Ontario Research Foundation, Mississauga, Ontario.

1.2 PURPOSE OF THE INCINERATION PROCESS

It is important for the reader to understand the contribution which the rotary kiln incineration system will make as part of a treatment philosophy, in ensuring that OWMC's Facility can treat Ontario's special wastes in an environmentally safe manner. This is explained in the following paragraphs.

Organic wastes which are delivered to OWMC's Facility for treatment and disposal will be destroyed by high temperature thermal oxidation using a rotary kiln incineration system. The incineration plant provides the capability of destroying any organic contaminants delivered to the Facility, whether they be in solid or liquid, pumpable or non-pumpable form, whether they be in concentrated raw wastes or bound in primarily inorganic residues arising from physical/chemical treatment processes, or even trace organic contaminants of concern remaining in the treated effluent following physical/chemical treatment, if so required in order to protect human health and the environment.

The incineration system will include provisions for cooling the gaseous products of combustion (flue gases) and for treating the cooled flue gases to remove contaminants, prior to the cleaned gases being discharged to atmosphere via a stack.

Inorganic residues from the incineration plant will be disposed of in an engineered landfill, together with residues from the physical/chemical processes, after they have been solidified to produce a material which is both physically and chemically stable under conditions expected at the engineered landfill, and to thereby minimize the level of residual contaminants in landfill leachate.

CHAPTER 2
BASIS FOR TECHNOLOGY SELECTION AND CONCEPTUAL DESIGN

2.1 INTRODUCTION

An important aspect of the evaluation and selection of appropriate components for OWMC's rotary kiln incineration system is to define the framework within which the selected component technologies will be expected to operate. This framework is defined by:

- o OWMC's philosophies,
- o the type and quantities of wastes which are likely to require incineration,
- o the particular treatment objectives, philosophies and assumptions (premises and postulates) which have been applied to the design of the incineration plant, and
- o the capabilities of the incineration plant in relation to those of the other major process areas (i.e. physical/chemical treatment and solidification areas) within OWMC's Facility.

2.2 OWMC PHILOSOPHY

OWMC has developed several basic planning principles and guidelines which are central to technology selection and process design in all areas of the proposed treatment Facility. The following points summarize these key treatment philosophies.

- OWMC's primary responsibility is to establish and operate a liquid industrial waste and hazardous waste management system in Ontario. It has no responsibility for managing municipal solid waste or radio-active waste, nor is it a regulator of other industrial waste management systems (Ref: OWMC[3]).

- OWMC Facilities, no matter how large or small they ultimately may be, must be designed to handle all types of special waste. This full service capability is inherent in OWMC's responsibility as a provincial crown agency.

- Wastes must undergo treatment to the fullest extent possible, using the best available proven technologies, prior to the safe disposal of the remaining treated residues.

- It is the Corporation's goal, in order of priority, to:

  - minimize risk to human health,
  - minimize environmental impacts, and
  - minimize financial costs to OWMC and the people of Ontario.

2.3 WASTE PROFILE

OWMC commissioned a waste study in Phase 1 of the Facilities Development Process which proposed a classification of Ontario special waste and estimated the types and quantities of each (Ref: OWMC[2,3,10], The Proctor & Redfern Group[11]). Additional work has subsequently been conducted to improve available data and to refine OWMC's assumptions on the quantities and characteristics of wastes it will be receiving for treatment and disposal. These most recent data have been used as a basis for ensuring that the rotary kiln incineration system will have the necessary processes, capacity and flexibility to respond to the waste treatment and disposal needs of industries in Ontario.

Table 1 summarizes the waste classes and quantities which are likely candidates for incineration.

Conclusions drawn from the existing waste profile information have had an influence on the technology selection and process design of the incineration plant. These are summarized in Section 2.5 (pg. 10). It is recognized that the nature and quantity of the various waste types which arrive at OWMC's Facility may differ from that presently envisaged and will likely continue to change throughout its operating life. The ability of the selected rotary kiln incineration system to handle such variations was considered essential and is further discussed in Section 3.3.3 (pg. 22).

2.4 PREMISES

Premises are the information provided by OWMC or by other studies undertaken by the Corporation which have been taken as points of departure for new work. OWMC's basic planning principles and guidelines presented in Section 2.2 (pg. 5) are premises which apply to OWMC's Facility as a whole including the incineration plant. The following additional premises have also been used as starting points for technology selection and process design in the incineration plant.

- The incineration plant will be designed to treat special wastes which are primarily organic in nature. Wastes which are primarily inorganic in nature will be sent to the physical/chemical plant for treatment. Inorganic residues from the incineration plant will be further treated, as required, in the physical/chemical treatment and/or solidification plants prior to being disposed of in an engineered landfill. Incinerator slag will be disposed of directly in the engineered landfill unless it is shown that the leachability characteristics of this residue can be further improved by prior treatment.

TABLE 1
CANDIDATE WASTES FOR INCINERATION

OWMC CLASS	DESCRIPTION	TYPICAL TOTAL QUANTITY EXPECTED AT OWMC FACILITY (t/a)	TYPICAL WASTE QUANTITIES ORGANICS TO INCINERATION (t/a)	INORGANICS TO PHYS/CHEM (t/a)	INORGANIC RESIDUES TO SOLIDIFICATION (t/a)
1	Organic Waste Sludges and Still Bottoms	11 050	9 580	1 470	0
2	Solvents and Organic Solutions	3 330	3 330	0	0
3	Oil and Grease	880	880	0	0
4	Oil and Water Mixtures	3 530	3 530	0	0
5	Organic and Oily Residues	6 030	3 790	2 240	0
6	Heavy Metal Solutions and Residuals	79 480	0	66 050	13 430(1)
7	Miscellaneous Chemicals and Products	3 100	860	2 240	0
8	Paint and Organic Residuals	5 030	4 750	280	0
9	Aqueous Solutions and Organics	1 790	600	1 190	0
10	Anion Complexes	1 070	0	1 070	0
11	Sludges and Inorganic Residuals	32 030	0	12 660	19 370(1)
12	Pesticide and Herbicide Waste	180	180	0	0
13	PCB Wastes	30	30	0	0
14	Clean Up Residuals	2 470	2 470	0	0
				87 200	32 800
	TOTALS	150 000	30 000	120 000	

Notes:

1. In many instances these are residues resulting from physical/chemical treatment at the waste generator's facility.
2. Residues from the physical/chemical treatment plant which require treatment by incineration, are omitted from the above table. These residues will be accommodated in the nominal capacity of the incineration system.
3. Waste quantities are derived from OWMC Waste Profile Information (November, 1984) and are rounded off to the nearest 10 t/a.

- The incineration plant will be designed for an initial capacity of 30 000 t/a of organic special wastes based on a total Facility capacity of 150 000 t/a.

- The initial incineration plant capacity will be achieved by the installation of a single rotary kiln incineration system.

- The ultimate design capacity of the incineration plant will be 60 000 t/a, and this will be achieved by installing a second incineration system of 30 000 t/a capacity.

- Space will be provided on the Facility for the installation of a second rotary kiln incineration system similar to that initially proposed.

- The arrival of wastes at the Facility will be scheduled in advance.

- The types and quantities of special wastes which could require treatment at the incineration plant have been defined to the extent possible by OWMC's Waste Profile information.

- The waste profile shown in bold face on Table 1 is typical of the types and quantities of waste the incineration plant could receive. However, variations may result from:

  - the effectiveness of OWMC's 4R program, which is to encourage industry in Ontario to reduce, recover, recycle and reuse industrial waste,
  - industry's response to market demands and to financial constraints,
  - process and manufacturing changes, and
  - changes in Provincial waste regulations.

On this basis it is important that the incineration plant design incorporate features such as:

- maximum flexibility,
- future expansion capability, and
- reserve storage and treatment capacity.

2.5 POSTULATES

Postulates are assumptions or hypotheses which are basic to the approach used to evaluate alternatives and arrive at an optimum process design. The key assumptions, treatment objectives and treatment philosophies which have influenced technology evaluations and process design for the incineration plant are summarized below:

o The incineration plant will be designed to achieve the following treatment objectives:

- To treat incoming special waste of a primarily organic nature such as to provide a Destruction and Removal Efficiency (DRE) of not less than 99.99% for each Principal Organic Hazardous Constituent (POHC) designated in the waste feed, consistent with the requirements of the US Environmental Protection Agency. (Ref: Federal Register Vol. 47, No. 122, 24 June 1982, page 27526). While most regulating authorities have set limits for the emission rate of organics to the atmosphere, the US Environmental Protection Agency is currently the only regulating authority that attempts to regulate incinerator performance by relating the organic emission from an incinerator to the organic feed rate of the incincerator (Destruction of Organics, pg. 212). It was decided in the early stages of conceptual design to adopt this performance requirement for OWMC's Facility.

- To treat flue gases from the combustion process so that contaminants such as particulates (dust), acid gases and inorganic metals are removed to the maximum extent possible using best available proven technology, prior to the flue gases

being discharged to atmosphere. The flue gas quality must ensure that the resulting point of impingement contaminant concentrations at least meet the requirements of the Environmental Protection Act of Ontario, RSO 1980, Regulation 308 (Ref: MOE[12]), including any provisional regulations or guidelines.

- To produce residues which can be treated by physical/chemical processes, including solidification, prior to them being safely disposed of in an engineered landfill.

- To incinerate organic residues from the physical/chemical treatment plant to the same treatment objectives established for special wastes.

- To ensure that treatment objectives can be carried out safely.

o Aqueous organic wastes which are not amenable to physical/chemical treatment will be incinerated. Similarly, batches of inorganic waste which contain unacceptable concentrations of organics even after treatment, may also be incinerated. The incineration system will therefore be equipped to dispose of contaminated water.

o The physical form and method of delivery to the Facility of organic special waste, has been estimated as follows, from OWMC's Waste data.

Waste Form	Method of Delivery	Tonnes/Annum (t/a)	Percentage of Organic Waste
Bulk Solids	Truck/Container	7 860	26.2
Solids and Sludges	Drums	10 200	34.0
Liquids	Drums	870	2.9
Liquids and Sludges	Tank Trucks	11 070	36.9
		30 000	100.0

The incineration system must therefore be designed to accommodate varying physical forms of waste including solids, sludges, and liquids, fed to the incineration process as bulk solids, in drums or via pumps. The rotary kiln incinerator provides this flexibility.

- Sizing of the incineration process components will be based on 7 000 operating hours a year and a capacity factor of 90%. Hence, the design capacity of the initial incineration system is 4.76 t/h calculated as follows:

$$\text{Design capacity} = \frac{30\,000}{7000 \times 0.9} = 4.76 \text{ t/h}$$

- The maximum continuous heat input of the incineration system will be based on waste having an average lower heating value (LHV) of 14 000 kJ/kg which has been estimated from OWMC's waste profile information. The unit will be capable of operating continuously at the resulting thermal capacity of 66.64 GJ/h.

- The incineration system must be capable of operating below its design capacity in recognition of the fact that quantities of organic waste delivered to the Facility will vary, and are expected to build-up over a period of years. The system will therefore be designed to operate in a safe, efficient and reliable manner at any capacity from 50% to 100% of its rated thermal capacity.

  Operational considerations associated with this requirement are discussed in Chapter 4, pg. 146.

- The incineration process will be designed to operate at temperatures of up to 1400°C and will normally operate above 1000°C in the rotary kiln and secondary combustion chamber prior to the introduction of secondary air. The temperature will be maintained above 1200°C when burning certain waste types, as further discussed in Chapter 4.

- The incineration system will be designed to accommodate the following variations in waste feed characteristics, based on an assessment of OWMC's waste data:
  - heating value variations from 11 000 kJ/kg to 42 000 kJ/kg without supplementary fuel firing. Below 11 000 kJ/kg supplementary fuel will be required.
  - water content varying up to 50% by weight of total waste feed.
  - inert solid content varying up to 30% by weight of total waste feed.

  Operational considerations associated with such variability in waste characteristics are discussed in Chapter 4 (pg. 146).

- The flue gas treatment system will be designed to remove particulate, heavy metals and acid gases from the flue gas produced when incinerating wastes types envisioned for OWMC's Facility. The normal and maximum concentrations of chlorine and sulphur expected in the organic waste were estimated based on an assessment of OWMC's waste data, and knowledge of what similar installations were being designed for in both Europe and North America. The resultant design basis is as follows:

	% Weight	
	Normal Operation	Maximum
Chlorine	5	15
Sulphur	1	3

- The incineration plant will operate in a continuous mode, 24 hours a day, 7 days a week.

- Analytical tests will be conducted on samples of waste prior to incineration to determine important parameters such as heating value, chlorine, sulphur, water and inorganic content, and concentrations of critical components such as certain metals. This will permit the preparation of daily "menus" of waste to be incinerated and thereby ensure that the design limitations of the incineration system in the destruction and removal of specific chemicals, is not exceeded.

- A range of criteria were used as a basis for evaluating and comparing alternative components for the incineration system. Emphasis was placed on four such criteria: performance, safety, flexibility and reliability to ensure that the processes selected represent the best available proven technology, in keeping with OWMC's objectives, and reflect OWMC's principal goals in minimizing risk to human health and impact on the environment.

- The manner in which the evaluation criteria address OWMC's goals and objectives is further discussed in Chapter 3 (pg. 17).

CHAPTER 3
TECHNOLOGY EVALUATION AND SELECTION

3.1 INTRODUCTION

The previous chapter outlined the framework within which the rotary kiln incineration system will be expected to operate. The following sections describe the methodology and criteria used to select the main process components of the incineration system which are best suited to this particular application. Chapter 3 also summarizes the results and conclusions of the technology evaluation process including the reasons for either accepting or rejecting each of the alternatives considered.

The main process components of a rotary kiln incineration system are:

- o a combustion system, comprising a rotary kiln and a secondary combustion chamber,
- o a flue gas cooling system, and
- o a flue gas treatment system.

While previous reports (Ref: OWMC[2,3], A. D. Little[4]) established the use of a rotary kiln incineration system at OWMC's Facility, these reports focused on the combustion system and did not examine alternative flue gas cooling and flue gas treatment systems. Chapter 3 of this report evaluates alternative technologies for the cooling and treatment of the flue gases discharged from the combustion system.

All three main components of the rotary kiln incineration system, namely the combustion system, flue gas cooling system and the flue gas

treatment system, are addressed in Chapter 4 of this report dealing with the design and optimization of the incineration plant.

3.2 METHODOLOGY

The following points summarize the methodology used to evaluate alternative technologies for the flue gas cooling and flue gas treatment components of the rotary kiln incineration system.

- o Establish the major treatment objectives and key treatment philosophies for the proposed incineration plant.

- o Establish criteria for technology selection.

- o Establish a "short list" of potentially suitable technologies and alternatives to these technologies.

- o Define specific treatment requirements for each stage of the rotary kiln incineration system and list alternative technologies which are potentially capable of meeting these objectives.

- o Identify alternative incineration system designs incorporating the shortlisted technologies.

- o Evaluate and rank the relative suitability of each conceptual system design according to the established criteria and select the preferred system for inclusion in the conceptual design.

3.3 CRITERIA FOR TECHNOLOGY SELECTION

It was considered essential that only those technologies which have been used previously in full scale waste treatment applications be given serious consideration for use in the incineration plant and some technologies were eliminated from further consideration based on this "screening" criterion alone. For this application, technologies are considered "proven" if they have performed satisfactorily for a period of one year on a similar scale and in a similar application.

Furthermore, to provide an additional measure of confidence in the incineration process, it was pre-determined that only those system designs which have been satisfactorily demonstrated in full scale incineration applications should be seriously considered for OWMC's incineration plant. This was considered important since the incineration process is a continuous high temperature process where the individual technologies form a complex dynamic system. By comparison, the physical/chemical treatment plant comprises a series of distinct unit operations, operated in a batchwise manner at essentially room temperature, and technologies which have been proven individually, but not as a system, can be assembled into a process system with high levels of confidence.

Alternative conceptual system designs were evaluated against the following technology evaluation criteria:

- o Performance
- o Safety
- o Flexibility
- o Reliability
- o Operational considerations
- o Economic and commercial considerations
- o Canadian and Ontario benefits

Higher weighting factors were given to the first four evaluation criteria (performance, safety, flexibility and reliability) in determining

a preferred system design best suited to OWMC's proposed treatment Facility. This approach ensured that OWMC's corporate goals (pg. 6) for the design of the treatment Facility were being adhered to in the design of the incineration plant.

A more detailed description of the technology evaluation criteria is provided below.

3.3.1 PERFORMANCE

This criterion recognizes and addresses three elements crucial to the establishment and operation of OWMC's treatment facility, namely that the technologies selected:

- o are those which are able to most effectively treat the wastes received,
- o can be operated in a manner which is efficient in the use of energy, utilities and reagents, and
- o produce minimum quantities of residues and in a form which is most amenable to further treatment, if required, prior to ultimate disposal.

This criterion also reflects the extent to which the technologies have been used elsewhere in full scale industrial waste treatment applications.

These objectives underly the sub-criteria into which the broad category of "performance" has been divided for technology evaluation purposes. These sub-criteria will ensure that OWMC's Facility minimizes impact on the environment in the following manner.

Most Effective Treatment

The characteristics of alternative rotary kiln incineration systems are compared on their relative ability to reduce residual contaminants of concern to the lowest practical level in the treated flue gas, for the broadest range of contaminants that may be expected in the waste feed.

A relatively high weighting has been given to this sub-criterion (50% of the total) in recognition of OWMC's desire to establish a treatment facility which most effectively deals with Ontario's special waste and thereby minimizes the negative effect on human health and the environment.

Efficiency: Energy, Utilities, Reagents

The relative efficiency of each process with respect to energy usage, utility requirements and reagent consumption is measured by this sub-criterion.

Minimum energy use and utility requirements are desirable, not only to minimize operating costs, but to reduce impact on the existing infrastructure of the surrounding environment, and in particular the host community, to the lowest possible level.

The minimization of reagent use is desirable since the reagents are themselves potentially hazardous chemicals and their presence adds to the potential for negative environmental impact of the Facility due to the following:

- Reagent transportation to the Facility and potential releases during storage and use at the Facility.

- The contribution which reagents make to the quantity of treatment residues requiring landfill disposal, the resulting incremental increase in landfill area requirements and associated environmental impact.

Residue Characteristics

Preference is given to technologies and process systems which produce the lowest quantities of residues or conversely, those that can detoxify and concentrate residual contaminants removed from the waste for disposal, to the greatest extent. Preference is also given to technologies which produce residues:

- o requiring minimum further treatment prior to disposal in the engineered landfill,

- o which are most amenable to subsequent treatment, if required,

- o which are in the most convenient physical form for subsequent treatment, and

- o which can be readily rendered both physically and chemically stable by solidification processes, prior to disposal in the landfill.

Selection of technologies and process systems having these characteristics will not only assure that the Facility design can operate in a cost effective manner, but also that the performance achieves OWMC's principle goals of minimizing risk to human health in the handling and treatment of residues at the Facility, and of minimizing potential for negative effects on the environment arising from ultimate treatment and disposal of these residues.

Extent Used Elsewhere

The extent to which the process system has been used elsewhere in full scale industrial incineration plants, is an extension of the "proven" screen used to develop the short list of potential technologies.

OWMC's definition of "proven" technology, as used in the screen, stipulates that a technology must have been commercially demonstrated to perform reliably for a period of at least 12 months on a scale and in a manner comparable with that required for OWMC's Facility before its consideration at a more detailed level. It is a means of establishing a list of technologies to be considered. This sub-criterion carries the logic behind the "proven screen" one step further. In order to ascertain with any degree of certainty, the impact a technology will have on the environment, it is necessary to draw from as reliable and extensive a data base as possible in predicting the performance of that technology. The more information available, the more certain OWMC can be on the performance and the environmental impact of a technology. Preference is therefore

given to those technologies which have an extensive history of satisfactory performance in similar process applications.

3.3.2 SAFETY

Results of evaluation by the "safety" criterion are the most obvious means by which OWMC measures the degree to which a technology achieves its first two corporate goals; to minimize risk to human health and to minimize impact on the environment. The criterion has been divided into two sub-criteria that correspond to these two goals, and have been given equal weighting in the evaluation process.

Occupational Risk

The occupational risk to employees at the Facility is of primary importance to OWMC, largely because the potential for negative consequences is the greatest for humans in closest contact with special waste at the Facility, during its handling, storage and treatment. This sub-criterion reflects OWMC's desire to minimize risk to human health.

Occupational risks may occur during normal plant conditions or during plant upsets. Risks during normal plant conditions addresses the potential for impact on the worker during everyday operation of the Facility and may cover a wide spectrum of possibilities. At the incineration plant, risk during normal operation might be experienced by the worker due to noise levels, or due to direct contact with wastes or waste residues such as fugitive dusts or fumes.

The measure of worker risk during upset conditions acknowledges that some degree of risk may be unavoidable when using certain technologies that are required to effectively treat Ontario's special wastes. Within the incineration plant, worker risks during upset conditions may result from hot water scalding due to a pipe fracture at the wet gas scrubber, or due to dust inhalation during the removal of blockages in residue conveyor systems. The inclusion of this element in the selection of technologies ensures that this risk is minimized.

While some risks during normal and upset conditions can be avoided by

selecting appropriate technologies, many more can be mitigated by design or operational procedures in the optimization of Facility design. Mitigation is dealt with in Chapter 4, System Design and Optimization.

Environmental Risk

Environmental risk during normal and process upset conditions encompasses the potential for risk, not only to the natural physical and biological environment, but risk to the surrounding human population as well, including the host community.

Technologies which provide the lowest potential for negative environmental impact will be ranked higher than other alternatives for this sub-criterion, in a manner which is consistent with OWMC's commitment to minimize risk to human health and the environment.

This sub-criterion also addresses environmental risks during both normal and process upset conditions. Environmental risk during normal operations is a measure of the threat to human health and the environment of a technology under normal operating conditions. Technologies are compared in terms of their potential for negative environmental effects in the long term, through gradual release of, and/or buildup of, contaminants in the receiving environment.

Environmental risk during upset conditions is primarily a measure of the potential for sudden contaminant release and the risk to the receiving environment of substances that may be released. In the incineration plant, such events may arise during a power failure or malfunction of the flue gas treatment system, although events of this nature can be mitigated by design or operational procedures, as further explained in Chapter 4, System Design and Optimization.

3.3.3 FLEXIBILITY

One of the premises which guided the Facility design was a requirement that the Facility have maximum flexibility to treat a wide range of wastes. This requirement is based on the knowledge that wastes received at OWMC's Facility will cover a broad spectrum of both physical and chemical forms.

The "flexibility" criterion therefore reflects the need to achieve OWMC's objectives of minimizing risk to human health and impact on the environment for a wide range of waste types and characteristics. It also assesses the ability of technologies to easily and safely handle variations in quantities of waste requiring treatment.

The following sub-criteria are used to measure the relative ability of alternative technologies and process systems in dealing with a wide range of waste types and quantities.

Waste Characteristics

This sub-criterion addresses the relative ability of alternative technologies and process systems in adapting to and accommodating variations in feed composition or type of waste. The variations that will inevitably occur in the type and characteristics of waste delivered to OWMC's Facility demand that technologies included in the Facility design have capability to reduce residual contaminant discharges to the lowest practical level for a wide range of waste characteristics.

Technologies which are least sensitive to changes in waste characteristics will be ranked highly against this sub-criterion.

Waste Quantities

The relative ability of alternative technologies in adapting to variations in the quantities of wastes requiring treatment, is measured by this sub-criterion.

OWMC cannot accurately predict the volumes of particular wastes it may receive, or the variations that may occur over time spans measured in years. It is desirable, therefore, that technologies be capable of effectively processing wastes over a range of feed rates.

This sub-criterion reflects in part, the relative ability of alternate technologies to operate satisfactorily at capacities significantly below their design capacity.

Rapid Startup/Shutdown

This sub-criterion recognizes that operational flexibility in achieving rapid startup and shutdown of process systems offers distinct advantages in achieving optimum utilization of treatment systems, particularly where they are operated in a batch treatment mode and/or for a limited number of hours/week. Rapid shutdown capability is also important when responding to process upsets requiring immediate response actions.

For the incineration plant, which is a continuous process system, the speed of process startup is governed by the rotary kiln incinerator i.e. the combustion system, and few differences are likely to exist between the alternative flue gas cooling and treatment systems, in respect to this sub-criterion.

3.3.4 RELIABILITY

The "reliability" criterion measures the ability of a technology to achieve anticipated results on a consistent basis. This criterion focuses on the physical components of potential technologies and alternative process systems, the extent of their maintenance requirements, the need for spare parts, the availability of reagents and spare parts, the general robustness of the design and its vulnerability to breakdown.

All of these factors influence the reliability of a process system and the ability of the treatment Facility to achieve all three of OWMC's corporate goals. They are reflected in the following five sub-criteria, many of which are to some extent interrelated.

Maintenance Requirements

This sub-criterion reflects a preference for technologies and process systems which minimize the amount and frequency of downtime required for maintenance. It is also desirable, where possible, to avoid the use of technologies involving complex maintenance procedures.

Spare Parts

Preference is given to technologies requiring the least number and lowest cost of spare parts inventory.

Availability of Spare Parts and Reagents

This sub-criterion reflects a reluctance to utilize technologies for which spare parts and/or reagents are not readily available. Delays in obtaining either parts or reagents could result in a component of OWMC's Facility being out of operation for an extended period, and this would adversely impact on OWMC's ability to achieve its corporate goals.

Robustness of Equipment

This sub-criterion ranks technologies by the susceptibility of their components to breakdown. Efficient processing of special wastes is dependent on the ability of the equipment to withstand the rigours of extended operation, exposure to a variety of special wastes and variations in process conditions without breaking down or requiring frequent maintenance. It also minimizes costs. This sub-criterion is therefore linked to all three of OWMC's goals.

Vulnerability To Process Upset/Breakdown

The rationale for this sub-criterion is similar to the preceding one, but focuses on the process itself as opposed to the items of equipment of which it is composed. In general, the more complex the technology and the more component parts that the process system has, the more vulnerable it is likely to be to process upset and/or breakdown.

3.3.5 OPERATIONS

The inclusion of this criterion is intended to reflect OWMC's desire to have a Facility which not only has the capability of treating special wastes to the highest practical standards, but also one which is highly operable in terms of its complexity and the extent to which it can be automated. The amount and availability of specialist startup assistance and operator training required for alternative technologies, is a further consideration.

This criterion therefore has a direct bearing on OWMC's ability to achieve its corporate goals once the Facility is in operation.

Complexity

From an operational viewpoint, preference is given to those technologies and process systems which have minimum component parts, are easily understood and simple to operate and maintain.

Degree of Automation

Ranking by this sub-criterion reflects the degree of operator involvement required to monitor and control the process, and the extent to which the operator has control over the process operations, particularly the quality of discharges released to the environment.

While not always practical, an automated process is usually desirable since it removes the potential for human error in waste processing. The ability to provide a process with automatic "fail-safe" and emergency shutdown systems is considered preferable to those relying on manual initiation of safety and shutdown procedures.

Startup Assistance

The extent of startup assistance and special operator training required is influenced by the complexity of Facility design and process operations.

While the nature of OWMC's Facility mandates a high level of startup assistance and special operator training by those having prior experience with the individual technologies and with similar treatment systems, preference will be given to those technologies and process systems which do not require an excessive amount of specialist input. The availability of resources to provide startup assistance and assist in operator training is a further consideration, particularly when considering the use of proprietary designs.

3.3.6 COMMERCIAL AND ECONOMIC

This criterion reflects for the most part, one of OWMC's corporate goals; the desire to minimize the cost of the Facility. Although cost is perceived as one of the negative impacts of the Facility on Ontario, this criterion is given a low weight relative to criteria that measure the minimization of impact on human health and the environment. The sub-

criteria used to compare the alternative technologies and process systems are further described below.

Restrictions on Use

Preference is given to those technologies where no restrictions exist on their use by OWMC for the present or any future applications.

Cost

A high weighting (70% of the total) has been given to this sub-criterion in recognition of the third of OWMC's corporate goals. The cost factor includes consideration of capital costs, operating costs, license fees, potential for return on investment and for energy recovery.

Supplier Competition and Reliability

The extent of supplier competition in the marketplace may have an indirect bearing on the cost to OWMC of including a given technology or process system in the Facility design. The reliability of known equipment or process suppliers may have an influence on the selection of a technology if it can only be obtained from a single source, i.e. the technological advantages may be tempered by concerns regarding the supplier's ability to honour contractual commitments.

Delivery

In order to ensure that some credit be given to a technology if it has a shorter delivery period than another, and could therefore permit a shorter engineering and construction schedule for the Facility, delivery was included as a sub-criterion to the Commercial and Economic criteria. Delivery was, however, given a very low weighting to prevent a technology with better performance or flexibility for instance, but with a longer delivery than another being rejected solely because of this longer delivery.

3.3.7 CANADIAN BENEFITS

Alternative technologies were examined to determine whether any benefits would be accrued to Canada, should one technology be selected over another.

This criterion is a measure of the potential positive impacts of the Facility.

The sub-criteria used to compare the alternative technologies and process systems are further described below.

Engineering

Preference is given to technologies which can be engineered in Canada.

Supply

Preference is given to those technologies which can be supplied and/or fabricated in Canada.

Technology Transfer

This sub-criteria reflects OWMC's preference to promote the transfer of knowhow to Canadian engineers and suppliers where such knowhow can only presently be obtained outside of Canada.

Where technologies are unavailable in Canada, preference is given to technologies and/or technology vendors who are able and willing to facilitate the transfer of knowhow to Canada.

3.3.8 APPLICATION OF THE TECHNOLOGY EVALUATION CRITERIA

Each of the evaluation criteria outlined in the previous sections were given a numerical weighting factor which reflects the order of importance of each criteria in the technology assessment process. The weighting factors that follow were reviewed and agreed upon with OWMC. Performance, safety, flexibility and reliability were considered to be the criteria of greatest importance in view of OWMC's stated goals to minimize risk to human health, minimize environmental impacts and minimize financial costs to OWMC and the people of Ontario. Performance, safety, flexibility and reliability were therefore given the highest overall weightings. Criteria relating to operations, commercial and economic considerations and Canadian benefits were assigned lower weighting factors consistent with these goals.

Criteria	Weighting Factor
Performance	20
Safety	20
Flexibility	20
Reliability	15
Operations	10
Commercial and Economic	10
Canadian Benefits	5

Each of the sub-criteria used to assess the relative performance, safety, flexibility, reliability, operations, commercial/economic and Canadian benefits associated with each alternative were also assigned weighting factors to facilitate the evaluation process. These weighting factors are summarized as follows:

Criteria	Sub Criteria	Weighting Factors
Performance		
	Most effective treatment	10
	Efficiency: energy, utilities, reagents	2
	Residue characteristics	2
	Extent used elsewhere	6
	Total	20
Safety		
	Occupational risk	10
	Environmental risk	10
	Total	20
Flexibility		
	Waste characteristics	7
	Waste quantities	7
	Rapid startup/shutdown	6
	Total	20

Criteria	Sub Criteria	Weighting Factors
Reliability		
	Maintenance requirements	1
	Spare parts	2
	Availability of spare parts and reagents	3
	Robustness of equipment	1
	Vulnerability to process upsets or breakdowns	8
	Total	15
Operations		
	Complexity	6
	Degree of automation	3
	Startup assistance	1
	Total	10
Commercial and Economic		
	Restrictions on use	1
	Cost	7
	Supplier competition and reliability	1
	Delivery	1
	Total	10
Canadian Benefits		
	Engineering	1
	Supply	2
	Technology transfer	2
	Total	5

Alternative flue gas cooling systems and flue gas treatment systems were compared for their relative abilities to fulfill each of the above-mentioned criteria by assigning rating values from 1 to 5. Those systems which were best suited to fulfilling a particular criterion were given the highest rating. Alternatives which were considered to be equivalent in their abilities to fulfill a particular criterion were given equal ratings.

The ratings for each alternative were multiplied by the weighting factors assigned to each criteria to arrive at a total weighted score for each system against each of the selection criteria.

The summation of the weighted scores for each alternative system provides a quantitative indication of the general relative suitability of each as a component of the rotary kiln incineration system. The higher the score the more suitable the alternative. The total weighted scores for each alternative system have been used for comparison purposes only to assess the overall suitability of one system against another.

It should be noted that this methodology has been adopted to assist in the technology selection process to enable all of the technology selection criteria to be accounted for in a rational manner during the evaluation process. This process has not eliminated the need for qualitative evaluation and engineering judgment in the selection of the preferred components of the rotary kiln incineration system. Such qualitative evaluations and judgements are based on experience with similar process systems and are necessary in the absence of equally detailed and quantifiable information on every one of the technologies and process systems under consideration, to avoid unnecessarily harsh penalization of one alternative solely because the information is not readily available.

3.4 LONG LIST OF AVAILABLE TECHNOLOGIES

A long list was compiled of available technologies which could be applicable to the cooling and treatment of flue gases resulting from the incineration of liquid industrial and hazardous waste. The resultant long list of generic technologies is as follows:

Flue Gas Cooling Technologies

- o air injection
- o indirect gas/air heat exchange
- o controlled evaporative water cooling (dry bottom cooling tower)
- o uncontrolled evaporative water cooling (wet bottom quench tower)
- o waste heat recovery boiler, - convective type
- o waste heat recovery boiler, - radiant type

Flue Gas Treatment Technologies

- o "knock-out" chamber
- o mechanical cyclone
- o mechanical multi cyclones
- o electrostatic precipitator (dry)
- o wet electrostatic precipitator
- o fabric filter
- o wet scrubber (disposable reagent)
- o wet scrubber (regenerable reagent)
- o dry scrubber
- o semi-dry scrubber
- o semi-dry scrubber NO_x removal
- o electrostatically augmented scrubbers
- o selective catalytic reduction
- o irradiation processes

The long list excludes specific proprietary designs except where such designs embrace the overall generic technology.

3.5 SELECTION OF SHORT LIST OF POTENTIALLY SUITABLE TECHNOLOGIES

3.5.1 PROVEN TECHNOLOGY "SCREEN"

Many of the technologies in the long list have been proven in full scale incineration systems of various types. However, some of the technologies listed do not meet the "proven technology" criterion, i.e. they have not been commercially demonstrated to perform reliably for a period of at least 12 months on a scale and in a manner comparable with that required for OWMC's Facility. These technologies were eliminated from consideration at the present time based on this factor alone:

- o wet scrubber (regenerable reagent)
- o semi-dry scrubber NO_x removal
- o selective catalytic reduction
- o irradiation processes

A brief description of the above mentioned technologies is presented in the following paragraphs.

Wet Scrubber (Regenerable Reagent)

Most of the wet scrubber systems used for industrial applications, including industrial waste incineration plants, use sodium based reagents such as caustic soda for the removal of sulphur dioxide. The wet scrubber system included in the short list of potentially suitable technologies (pg. 48) would also use a sodium based reagent.

There are several advantages of using sodium based reagents in wet scrubbers (Ref: Power[13]). These include the following:

- o Sodium is the most efficient of commercial reagents in removing sulphur dioxide, and the chemistry is relatively simple.

- They are liquid based systems, as opposed to slurry based systems using lime as the reagent, making for scale-free operation and fewer components.

- Such systems can handle wider variations in flue gas composition.

- Industrial systems are often smaller than large utility power plant applications and the higher cost of sodium based reagents is not a major disadvantage (i.e. operability, reliability and flexibility considerations justify the extra operating costs).

Several processes have been developed (Ref: Power[13]) which permit scrubber reagent to be regenerated and reused. In most cases the objective is to:

- use liquid based reagents such as caustic soda in the scrubber, thereby avoiding erosion, scaling and plugging problems so often experienced with lime slurry scrubber systems,

- reduce reagent costs by regenerating the reagent for reuse,

- provide a disposable product in a solid or semi-solid form, or to

- produce a marketable by-product such as sulphur or gypsum.

The economics of scale favour the use of such systems on large utility power plant applications rather than smaller industrial installations. However, operational problems have been experienced with such systems and reliability is a concern. The processes are intolerant of impurities in the flue gas and this may also be a problem if a saleable product is being produced. Clearly this would be a major concern in applying such technologies to an industrial waste incineration plant.

Hence, most large utility power plant operators have focussed on wet scrubber systems with disposable reagents.

Wet scrubbers with regenerable reagent systems have been eliminated from the short list of potentially suitable technologies since there is no record of them having been utilized on an industrial waste incineration plant of the type proposed for OWMC's Facility. The increased complexity and the effect that these systems might have on reliability, would be a significant concern.

Semi Dry Scrubber NO_x Removal

A process aimed at the removal of nitrogen oxides (NO_x) from combustion flue gas, involves relatively minor modifications to the conventional semi-dry scrubbing system. Niro Atomizer A/S of Copenhagen, Denmark have demonstrated this process at two USA utility power plant installations (Ref: Power[14]).

The system requires no major additional components beyond those already included in the semi-dry scrubber system, but involves the addition of sodium hydroxide to the lime slurry reagent. An increase in plume opacity however was observed during tests (Ref: Power[14]).

The suitability of this process to industrial waste incineration systems is unclear, since the hydrogen chloride content (HCl) of the flue gases may preferentially consume the reagent.

To our knowledge, this system has not been tried on industrial waste incinerators and has therefore been excluded from the short list of potentially suitable technologies. It may however hold potential for the future and should for this reason be kept in mind in selecting a flue gas treatment system for OWMC's incineration plant, since there may be possibilities to incorporate this feature at a later date.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) is considered to be one of the more advanced technologies for the removal of nitrogen oxides (NO_x) from the flue gases of combustion systems. The process is directed mainly at large utility power plant applications where large volume emissions of NO_x are a concern.

The SCR process converts NO_x to elemental nitrogen and water by using ammonia as a reducing agent in the presence of a catalyst at flue gas temperatures of between 260 - 370°C (Ref: Power[15]). Ammonia vapour is mixed with flue gas ahead of the catalyst bed, and NO_x removal is primarily governed by the quantity of ammonia injected.

Over 90% NO_x removal has been consistently achieved in 18 000 hours of operation on a unit of Southern California Edison Company's Huntington Beach thermal power plant. Control of ammonia injection appears to be the most difficult part of the operation, to avoid unreacted ammonia from being emitted to atmosphere (Ref: Power[15]).

This and other similar emerging technologies for the removal of nitrogen oxides from flue gases have been eliminated from the short list of potentially suitable technologies since there is no experience with such systems on industrial waste incineration plants and the technology does not meet OWMC's criteria that only proven technology be considered.

Irradiation Processes

Different types of irradiation processes are being developed for the simultaneous removal of nitrogen oxides (NO_x) and sulphur dioxide (SO_2) from combustion flue gases. The processes are targeted at large utility power plant applications.

Two electron beam processes are at the pilot plant stage in the USA (Ref: Power[14]). In one process developed by Research Cottrell Inc., high energy electrons from an electron beam, located between a lime spray dryer/ reactor and a fabric filter, excite flue gas molecules producing an abundant and reactive supply of ions and free atoms. Oxygen containing radicals and free atoms are then able to convert $SO_2^=$ and NO_x^- to higher oxygen levels, such as the acid forming molecules $SO_3^=$ and NO_3^-, which readily react with the alkalinity in the lime or in the flyash.

These reactions are enhanced by low temperature, high humidity conditions following the spray dryer, and the fabric filter collects the flyash, reaction products and unspent reagents. About half the SO_2 removal

and virtually all of the NO_x removal takes place in the solid "cake" which forms on the filtercloth. The system is expected to achieve 90% reduction of both NO_x and SO_2 emissions (Ref: Power[14]).

Another electron beam process developed by Ebara International Corporation (Ref: Power[14]) uses anhydrous ammonia, instead of lime, and this is injected into flue gas prior to a gas cooling/humidification step. The flue gases pass through an electron beam reactor and then through a fabric filter where the reaction products, ammonium nitrate and ammonium sulphate, are collected and removed. The product from this process is a potentially marketable fertilizer.

Concord Scientific Corporation of Toronto, Ontario has developed a process based on ultraviolet irradiation instead of electron-beam treatment (Ref: Power[16]). The ultraviolet radiation converts NO_x and SO_2 to their acid forming counterparts which are then neutralized by ammonia or other reagents such as lime in either a wet or dry scrubbing system.

These technologies have been eliminated from the short list of potentially suitable technologies since they do not satisfy the proven technology criterion. All of these processes are in the development stage.

3.5.2 BEST AVAILABLE TECHNOLOGY "SCREEN"

A number of other technologies have been used on incineration applications in the past, but are not presently considered to represent "best available proven technology" for industrial waste incineration systems of the type planned by OWMC. The functions which they perform are accomplished more effectively by other technologies listed i.e. there are obvious unequivocally better alternative technologies. These technologies were therefore eliminated from consideration at the present time:

- o "knock-out" chamber
- o mechanical cyclone
- o mechanical multi-cyclone
- o dry scrubbing

One of the flue gas cooling technologies listed, namely indirect gas/air heat exchange, has been used in a limited manner on hazardous waste incineration systems. This type of gas cooling system is prone to corrosion and buildup of deposits (fouling) of heat exchange surfaces. It has therefore been eliminated from further consideration at the present time.

A brief description of the above mentioned technologies is presented in the following paragraphs along with specific reasons why each has been omitted from the short list of potentially suitable technologies.

"Knock Out" Chamber

"Knock-out" chambers are employed to remove particulate material from incinerator flue gases by a combination of any one or more of the following means:

- Abruptly changing the direction of gas flow, thereby removing the particulates by inertia/gravitational force.

- Reducing the gas velocity thereby permitting the particulates to "fall out" of the gas by gravitational force. These devices are also known as "settlement chambers".

- A combination of the foregoing in conjunction with a "curtain" of water sprays through which the gases are required to pass.

This type of particulate removal system has been employed on many small capacity incinerators in the past. Their application is very limited in modern incineration plant installations, although it could be argued that the secondary combustion chamber of some designs of rotary kiln incinerators, also acts as a settlement chamber for heavy solid particles.

This technology has been eliminated from the short list of potentially suitable technologies since the removal of particulate material is known to be accomplished much more effectively by other technologies listed.

"Knock-out" chambers are also ineffective in the removal of fine particulates which are of concern due to their heavy metals content.

Mechanical Cyclone

The mechanical cyclone is a well proven technology for the removal of particulate material from flue gases in many industrial applications. Flue gas enters the cyclone tangentically at high velocity, thereby creating a cyclonic movement which "throws" particulate material to the wall of the cyclone by centrifugal force. The clean gas is removed from the central axis of the cyclone while the solid material is removed from a hopper located beneath the unit.

This method of particulate removal device was commonly used on combustion equipment, including incinerators, prior to the development of more effective technologies such as electrostatic precipitators and fabric filters. Mechanical cyclones are inefficient in removing particulates in the smaller size range and the performance also reduces significantly at part load operation.

High temperature cyclones, located directly following incinerator combustion chambers, have been used to protect downstream equipment including waste heat recovery boilers, from excessive solids loading in special applications. However, modern industrial waste incinerators are equipped with waste heat recovery boilers that can tolerate the solids loading experienced in flue gases, without the need for any prior removal of solids.

The regional hazardous waste incineration plant of Hessische Industriemull GmbH (HIM), at Biebesheim, West Germany (Ref: Scharsach[17]) includes a flue gas treatment plant having mechanical cyclones for the removal of contaminants in dry solid form. While experience at this installation has been most satisfactory, the owners intend to install an electrostatic precipitator rather than cyclones on a planned future unit, since system performance is expected to be further enhanced by this design improvement.

Mechanical cyclones have therefore been eliminated from the short list of potentially suitable technologies since the removal of particulate material is known to be accomplished much more effectively by other technologies listed. This does not preclude the consideration of cyclones as a pre-treatment, if so required during system design and optimization.

Mechanical Multi-Cyclone

Multi-cyclones are similar in concept to the mechanical cyclones described on the previous page, but are arranged in modules comprising many individual small units. Various designs exist and many include "swirling vanes" at the gas inlet to impart required rotation to the gas flow for the removal of particulates.

The modules of multi-cyclones can normally be configured to provide higher removal efficiencies in the removal of particulates than larger individual mechanical cyclones. They can also be arranged to isolate sections at part load operation, thereby reducing the detrimental effects of part load on performance.

However, there are many instances where multi-cyclones have become heavily fouled and even totally blocked by solid deposits which are "sticky" due to their chemical properties or moisture content. Multi-cyclones are still relatively inefficient in the removal of fine particulates.

Multi-cyclones have been eliminated from the short list of potentially suitable technologies since the removal of particulate material is known to be accomplished much more effectively by other technologies listed.

Dry Scrubbing

Dry scrubbing of flue gases is achieved by injecting a chemical reagent such as lime, in dry powder form, either directly into the combustion process or into a reactor vessel designed to provide intimate mixing of flue gases with the reagent. A portion of the reagent combines with acid gases such as hydrogen chloride and sulphur dioxide, to form solid compounds such as calcium chloride and calcium sulphate which are then

removed by downstream particulate removal devices, usually an electrostatic precipitator or a fabric filter.

The process has been demonstrated in pilot installations for the removal of sulphur dioxide from combustion flue gases resulting from coal fired steam generators. This involves the injection of lime into the combustion process. Sulphur dioxide removal efficiencies in the order of 50% have been achieved by such systems (Ref: Lee[18]).

Reduction of hydrochloric acid emissions from municipal refuse incinerators by the addition of calcium carbonate to the waste, has been satisfactorily demonstrated in full scale applications although removal efficiencies are quite modest (i.e. < 50%). (Ref: Gaudreau et. al.[19])

Other systems employing this technology for the removal of acid gases, are typified by the installation at Sysav, Sweden, where dry lime powder is introduced to the flue gases from a municipal garbage incinerator, in a reactor. The dry reaction products are removed from the system by an electrostatic precipitator and a fabric filter arranged in series. Typical acid gas removal efficiencies of 80% for hydrogen chloride, 50% for sulphur dioxide and 75% for hydrogen fluoride have been reported. (Ref: Shimell[20])

Industrial waste incinerators at a facility owned by GEREP, near Paris, France, are equipped with dry scrubbers involving limestone injection ahead of fabric filters. These units, which include a rotary kiln incineration system and a liquid injection system, have been equipped with dry scrubbers since 1981. (Ref: Sloan[21])

Comparison of dry scrubber systems with semi-dry scrubber systems have shown that the latter is significantly more effective in the removal of acid gases (Ref: Scharsach[22]). However, dry processes can be attractive for the treatment of flue gases resulting from municipal garbage incinerators where the acid gas concentrations in the raw gas are not as high as those experienced in industrial incinerators, and a lower removal efficiency is often acceptable.

This technology has been eliminated from the short list of potentially suitable technologies since little information is available on its use on industrial waste incinerators of the type proposed by OWMC. The removal of acid gases is known to be accomplished much more effectively by other technologies listed.

Indirect Gas/Air Heat Exchange

Gas to air heat exchangers are used extensively on a wide range of process industry applications, but infrequently on incineration systems. Such applications are usually confined to the cooling of relatively "clean" gases which will not result in deposition of solids (fouling) within the tubular heat exchanger, and often involve low temperature heat recovery systems (air heaters).

Tubular heat exchangers of this type are normally arranged with gases passing through large bore tubes (75 mm diameter or larger) for high temperature "highly fouling" applications, and more frequently with gases passing over tube bundles for low temperature "low fouling" applications.

The utilization of this technology in the high temperature environment existing prior to the flue gas treatment system of an industrial waste incinerator, is quite unusual. One such application at the liquid injection incinerator of Tricil, at Sarnia, Ontario (Ref: Redhead[23]), is believed to be operating satisfactorily. However, since this is a liquid injection incinerator, gas side deposition is expected to be less of a concern than for OWMC's rotary kiln incineration system involving the destruction of wastes having potentially high inert solids content.

In addition to the gas side fouling problems previously described, both high and low temperature corrosion can be a major concern on heat exchangers of this type in the onerous gaseous environment experienced in industrial waste incinerators, upstream of the flue gas cleaning system.

Indirect gas/air heat exchangers have been eliminated from the short list of potentially suitable technologies since the technology has not been proven in a hazardous waste incineration system of the rotary kiln type,

and considerable uncertainty exists regarding potential gas side fouling and corrosion problems which might be experienced in such an application.

3.5.3 SUMMARY

The long list of six flue gas cooling technologies and fourteen flue gas treatment technologies has been reduced to a shorter list of five potentially suitable flue gas cooling technologies and six potentially suitable flue gas treatment technologies.

The resulting "short-list" of potentially suitable technologies is as follows:

Flue Gas Cooling Technologies

- o air injection
- o controlled evaporative water cooling
- o uncontrolled evaporative water cooling
- o waste heat recovery boiler, - convective type
- o waste heat recovery boiler, - radiant type

Flue Gas Treatment Technologies

- o electrostatic precipitator (dry)
- o wet electrostatic precipitator
- o fabric filter
- o wet scrubber (disposable reagent)
- o semi-dry scrubber
- o electrostatically augmented scrubber

All of these technologies have been used commercially in full scale industrial waste incineration systems.

3.6 EVALUATION OF POTENTIALLY SUITABLE TECHNOLOGIES

As previously indicated, the rotary kiln incineration system has three main process components, namely:

- o a combustion system, comprising a rotary kiln and secondary combustion chamber,
- o a flue gas cooling system, and
- o a flue gas treatment system.

The short list of potentially suitable technologies identifies candidate technologies for the flue gas cooling component and the flue gas treatment component of the total process system. However, this representation of the total incineration system is also far more simplistic than is actually the case, and the flue gas treatment component can be further divided into distinct functions. The optimum incineration process system will therefore consist of several stages each contributing to the overall treatment objective.

The method employed for this technology evaluation procedure is as follows:

- o Define the process requirements, as functional stages which together form the incineration process system.

- o Identify, from the list of potentially suitable technologies, those which are capable of fulfilling each functional stage of the incineration process system.

- o Identify alternative incineration system designs incorporating the shortlisted technologies. As previously indicated (pg. 17), only those incineration system designs which have been satisfactorily demonstrated in similar full scale incineration applications were seriously considered.

- o Prepare conceptual process designs, obtain technical data and cost data pertinent to each from reputable process and equipment suppliers.

- o Select the rotary kiln incineration system which best satisfies the evaluation criteria and sub-criteria as outlined in Section 3.3 (pg. 17).

The functional stages which together form the incineration process system are discussed in the following paragraphs, together with those potentially suitable technologies which are capable of fulfilling each stage. The alternative incineration system designs identified for evaluation purposes are described in Section 3.6.2 (pg. 49), and evaluated in Section 3.6.3 (pg. 77). The results of the evaluation procedure are presented in Section 3.7 (pg. 95).

3.6.1 PROCESS REQUIREMENTS

The combustion process which takes place in the combustion component of the incineration system will be fully described in Chapter 4 of this report. It is important to recognize however, that this process also occurs in a staged manner and that the gas temperatures vary throughout the staged combustion process. It is sufficient to understand at this point, that the flue gases leaving the combustion component of the incineration system may vary in temperature between 900°C and 1250°C, and that these gases must be cooled to below 400°C in order to be treated by most modern flue gas treatment systems.

Flue gas which results from the combustion process consists predominantly of nitrogen and oxygen from the combustion air, plus carbon dioxide and water vapour formed by combustion of the waste. The flue gas also contains contaminants which can be broadly grouped as follows:

- o Particulates - these result from inorganic material contained in the waste and which become entrained in the flue gas.

- o Acid gases - these include hydrogen chloride and sulphur dioxide which result from the combustion of waste containing chlorine and sulphur respectively.

- o Heavy metals - these include such metals as lead, zinc and mercury, plus others which may exist in waste and are present in the gas stream in either solid or vapour form.

- o Nitrogen oxides - these result from nitrogen in the waste and also from the thermal oxidation of nitrogen in the air.

- o Trace organics - organic materials are destroyed in the combustion process and only trace quantities remain in the flue gas.

Hence, the primary purpose of the flue gas treatment system is to remove, to the extent possible, contaminants in the form of particulates, acid gases and heavy metals from the flue gas prior to the cleaned gas being discharged to atmosphere. Nitrogen oxides can be controlled only to a limited extent in industrial waste incinerators by adjustments to feed rates of high nitrogen containing wastes and by adjusting combustion conditions. Organic emissions are controlled predominantly by combustion conditions in the rotary kiln and secondary combustion chamber.

The quantity and nature of particulates, acid gases and heavy metals contained in the "raw" untreated flue gas as it leaves the combustion component of incineration process is directly related to the characteristics of the waste being incinerated. It is therefore essential that the processes selected to achieve the removal of these contaminants from the raw flue gases must be capable of dealing with a wide range of contaminant concentrations (quantity) and types, since the precise nature of the wastes are not presently known and will continue to change even after the Facility is in operation.

The rotary kiln incineration system can be divided into a series of distinct functional stages consistent with the preceding discussion. These stages, related to the three main component parts of the incineration system, are as follows:

Combustion System

The combustion system will, as previously mentioned, be thoroughly dealt with in Chapter 4 and is not being considered in this technology evaluation, since rotary kiln incineration has been selected in previous studies conducted for OWMC. However, the combustion system has two principle stages, namely:

- o primary stage (rotary kiln), and
- o secondary stage (secondary combustion chamber).

Flue Gas Cooling System

The flue gas cooling system can have one or more stages employing any of the short listed technologies as indicated below.

- o primary stage:
  - air injection
  - controlled evaporative water cooling
  - uncontrolled evaporative water cooling
  - waste heat recovery boiler, - radiant type
- o secondary stage:
  - air injection
  - controlled evaporative water cooling
  - uncontrolled evaporative water cooling
  - waste heat recovery boiler, - convective type

Not all of the technologies listed under "primary stage" can be combined with some of the technologies listed under "secondary stage".

Flue Gas Treatment System

The flue gas treatment system must have three distinct functional stages for removal of particulates, acid gases and heavy metal contaminants.

Heavy metals tend to condense out onto particulate material as the gases are progressively cooled, and hence the removal of particulates also effects the removal of heavy metals. However, heavy metals also concentrate in the sub-micron sized particles which are not as effectively removed by some types of particulate removal technologies. For this reason, the technologies listed below as being suitable for heavy metal removal, have the capability of removing sub-micron particulates including aerosols of volatile metals which can form as the flue gas is cooled.

- o particulate removal stage:- electrostatic precipitator (dry)
  - fabric filter
  - wet scrubber
- o acid gas removal stage:
  - wet scrubber
  - semi-dry scrubbing
- o heavy metal removal stage:- fabric filter
  - wet electrostatic precipitator
  - electrostatically augmented scrubbers
  - wet scrubbers

Wet electrostatic precipitators and electrostatically augmented scrubbers have been excluded from the candidate technologies for the particulate removal stage, since they have some operational constraints in dealing with heavy particulate loadings, and their application on industrial waste incineration plants, has been confined to the removal of low concentrations of fine particulate material.

Wet scrubbers have been included as a candidate technology for heavy metal removal, since some scrubber designs incorporate devices specifically for the removal of fine particulate material, including aerosols.

Descriptions of alternative rotary kiln incineration systems incorporating the potentially suitable technologies identified in Section 3.5.3 (pg. 43) and in the functional stages identified in Section 3.6.1 (pg. 45) are outlined in Section 3.6.2.

3.6.2 ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

Only those incineration system designs which have been satisfactorily demonstrated in similar full scale applications were seriously considered for OWMC's incineration plant. While the overall objective of the evaluation process was to select an incineration system which would minimize impact on the environment, the alternative process configurations were also selected with the following objectives:

- To permit comparison of incineration systems having energy recovery in the form of steam as part of the flue gas cooling system, with incineration systems which do not have energy recovery.

- To permit comparison of two different designs of waste heat recovery boiler, namely radiant designs and convective designs. This was required since some of the Incineration Technology Consultants, that were considered by OWMC, had strong preferences for one type or the other.

- To permit comparison of several different proven flue gas treatment systems.

The alternative system designs selected to meet these objectives are summarized on Table 2 (pg. 51) and illustrated diagramatically on Figures 1 through 8 (pgs. 53 to 75).

Preliminary process designs were established for each alternative, thereby providing a basis for meaningful comparison. Conservative assumptions were made for the purpose of process design and in comparing capital and operating costs for each alternative process system. The most pertinent assumptions are as follows:

- Flue gas quality following treatment was to be <u>at least</u> equal to, or better than the following:

Hydrogen Chloride	- 50 mg/Nm^3
Sulphur Dioxide	- 200 mg/Nm^3

Hydrogen Fluoride	-	5 mg/Nm^3
Particulate Material	-	50 mg/Nm^3

(All values corrected to 50% excess air, dry).

These minimum requirements were established following a review of regulations in other countries and an examination of actual performance data from operating facilities. It was considered that these requirements represented stringent, but nonetheless achievable criteria which should be acceptable for the purpose of this evaluation, while recognizing the opportunity for design optimization to achieve the lowest practical emissions during a later stage of the design development. The point of impingement concentrations that result from the above stack contaminant levels are significantly less than existing Ontario Regulations for the contaminants listed.

- While no specific treatment objectives were established for heavy metals, the demonstrated performance of alternative flue gas treatment systems in the removal of heavy metals, would be a major consideration in the evaluation process.

- Maximum concentration of lime slurry (as hydroxide) used in the flue gas treatment chemical handling systems was 15%.

- Maximum total dissolved solids in the flue gas treatment scrubber water was assumed to be 10% by weight unless otherwise stated. This was selected based on data from GSB Ebenhausen West Germany and discussion with scrubber suppliers.

- Liquid effluent from wet flue gas scrubbers was assumed to be concentrated up to 20% total dissolved solids by multi-stage evaporation in the physical/chemical treatment plant. The resultant concentrate would be solidified prior to being disposed of in the engineered landfill along with solidified solid residues from the incineration process. A sensitivity analysis (pg. 97)

TABLE 2
SUMMARY OF ALTERNATIVE INCINERATION SYSTEM DESIGNS

ALTERNATIVE	DESCRIPTION			
	Flue Gas Cooling Stage	Particulate Removal Stage	Acid Gas Removal Stage	Heavy Metal Removal Stage
1.	o radiant type heat recovery boiler	o electrostatic precipitator (dry)	o wet scrubber	o wet scrubber
2.	o air injection o convective type heat recovery boiler	o electrostatic precipitator (dry)	o wet scrubber	o wet scrubber
3.	o controlled evaporative water cooling	o electrostatic precipitator (dry)	o wet scrubber	o wet scrubber
4.	o radiant type heat recovery boiler	o electrostatic precipitator (dry)	o wet scrubber with spray dryer/reactor	o wet scrubber
5.	o radiant type heat recovery boiler	o wet scrubber	o wet scrubber	o wet scrubber
6.	o radiant type heat recovery boiler	o wet scrubber	o wet scrubber	o electrostatically augmented scrubber
7.	o radiant type heat recovery boiler	o wet scrubber	o wet scrubber	o wet electrostatic precipitator
8.	o radiant type heat recovery boiler	o fabric filter	o semi-dry scrubber	o fabric filter

Notes: 1. All alternatives include a rotary kiln incinerator with secondary combustion chamber.
2. Wet scrubber designs may be different for various alternatives.

examined the influence on technology evaluation, should it be possible to discharge treated scrubber effluent containing high dissolved solids, from the site.

- Steam generated in the waste heat recovery boiler is assumed to be used for building heating, boiler feedwater heating and deaeration, tank farm heating, incineration plant flue gas reheating and other process applications, as required. Excess steam would be condensed and the condensate reused wherever practical.

- The evaluation of energy recovery options was based on a fully integrated Facility comprising incineration, physical/chemical and solidification processes. Economic evaluations were based on the initial installation of one incineration process system.

Each alternative is further described in the following paragraphs, together with additional reasons for its consideration.

Alternative 1

The incineration system for Alternative 1 consists of a rotary kiln incinerator, a radiant waste heat recovery boiler, an electrostatic precipitator and a three stage wet scrubber arranged in series as illustrated on Figure 1.

This conceptual design was selected as a "base case" against which all other alternatives would be compared since it has been extensively used for many years on European industrial waste incineration systems, including the following:

- GSB, Ebenhausen, Bavaria, West Germany, operating since 1976. (Ref: The Proctor & Redfern Group[24])
- Bayer AG, Leverkusen, West Germany, operating since 1977. (Ref: The Proctor & Redfern Group[24], Fabian et. al.[25])

It should be noted that each of these plants have different proprietary designs of both heat recovery boiler, electrostatic

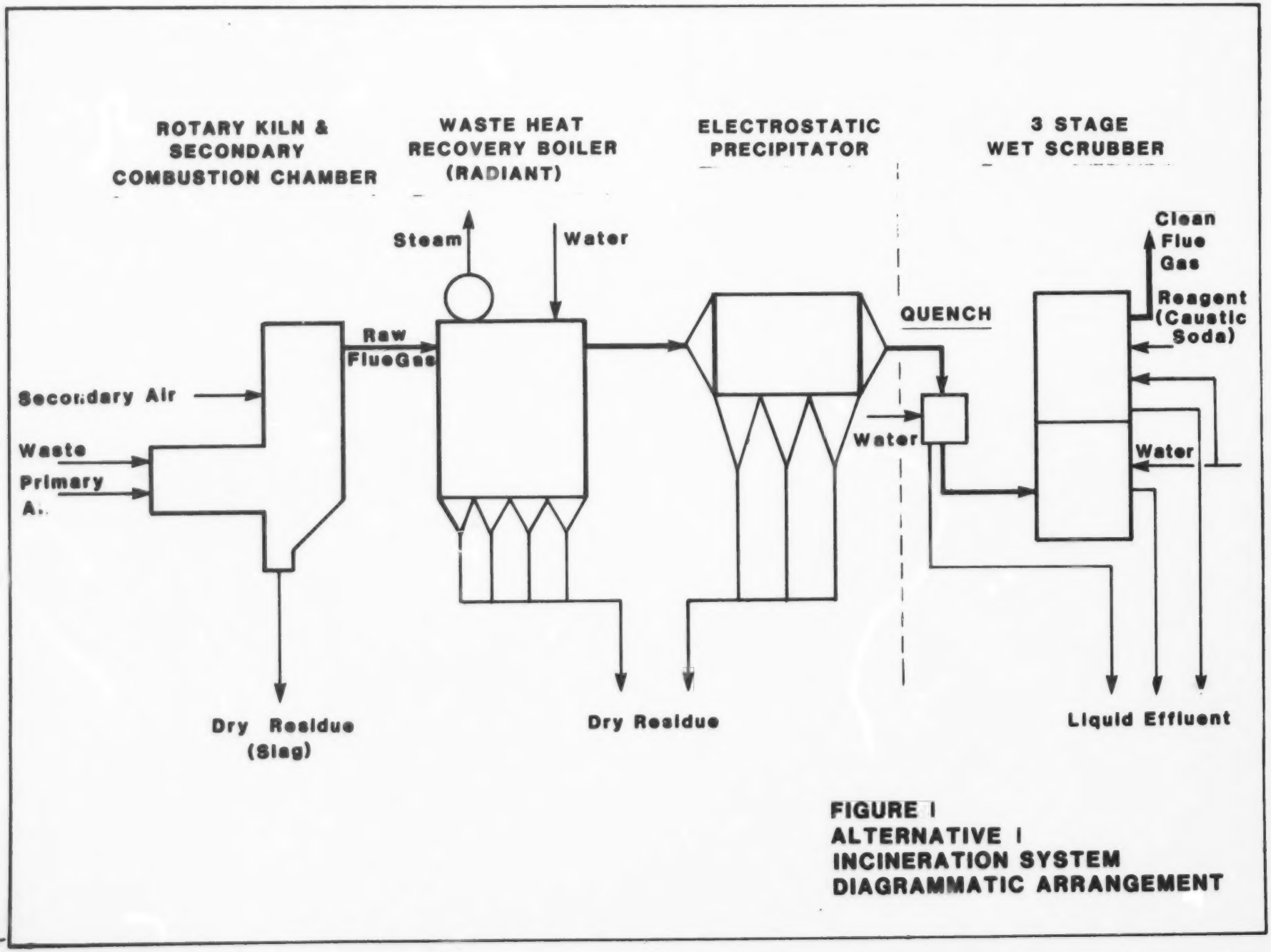


FIGURE I
ALTERNATIVE I
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

precipitator and wet scrubber, but the principal concept adopted is the same as Alternative 1.

In addition, the radiant type boiler concept, which will be described in further detail later (pg. 57), is used in industrial incineration facilities at BASF, Ludwigshafen, West Germany (Ref: Brenner et. al.[26]) and in many other industrial incineration facilities throughout Europe.

Raw flue gas enters the radiant waste heat recovery boiler at temperatures of up to 1250°C and more than 20 t/h of steam would be generated in cooling the flue gases down to 250°C at the boiler outlet.

Particulates which fall out of the flue gas as it passes through the boiler, plus impacted tube deposits removed from the boiler surfaces in normal operation, are discharged from the boiler via hoppers located beneath the unit. While various methods are employed to clean boiler tubes when the unit is in operation, it is not unusual to shut this type of boiler down every 3 - 4 months for cleaning.

The steam generation conditions of 2750 kPa and 300°C were chosen as high as possible, but within the range of proven experience on similar plants in Europe, so that the steam can be used on-site for steam turbine drives or for electric power generation should this be justified either initially or at a later date. The utilization of steam, selection of steam conditions, and the consideration of on-site power generation is discussed further in Chapter 4, dealing with the optimization of plant design. The steam generation conditions of the waste heat recovery boiler will be reviewed and finalized during detailed engineering.

Flue gas enters the electrostatic precipitator at approximately 250°C and passes between many vertically suspended plates which form the collecting electrodes of the precipitator. Gases are subjected to an intense electrical field established by discharge electrodes, located between each pair of collecting electrodes. A negative charge is imparted on the particulate material in the gas stream, and the particles are

attracted to the collecting electrodes where they either remain until dislodged by a rapping mechanism, or fall by gravity into hoppers located beneath the precipitator.

The precipitator would have two or three separate electrical fields arranged in series. The particulate material is removed in dry form from precipitator hoppers and some heavy metals will also be removed with the flyash as previously explained.

Acid gases and fine particulates, including aerosols of heavy metals, will be removed in a three stage wet gas scrubber. While there are many proprietary designs for scrubbers of this type, the three stages would typically comprise the following:

- o A quench section where flue gases are intimately mixed with large volumes of water, which reduces the temperature from 250°C to saturation temperature, about 60°C. Some residual particulate material and hydrogen chloride (HCl) will be removed from the flue gas in the quench section.

- o A packed bed section where flue gas flows up through packing material which is irrigated with water from the top. This section could alternatively be an open chamber with water sprays and some designers advocate such designs since they are more tolerant of high quantities of particulate material in the flue gas and less prone to fouling than packed bed types. However packed bed scrubbers are more compact. Hydrogen Chloride is removed by contact with water in this section.

- o A second packed bed or spray chamber, depending on the specific design, is supplied with a solution of caustic soda (NaOH) for the removal of sulphur dioxide (SO_2). This third and final stage would include a proprietary device for the removal of fine particulates including aerosols of heavy metals which may form as the gas is cooled in the scrubber.

While it was not the purpose of this evaluation to distinguish between proprietary designs of scrubber, the Ring Jet™ system developed by Ciba-Geigy and applied at the HIM Biebesheim incineration plant, is one such system for the removal of fine particulates and aerosols (Ref: Scharsach[17], Scharsach[22]).

The rationale for selection of sodium based wet scrubber systems for consideration in this evaluation is provided in Section 3.5.1 (pg. 33). The use of caustic soda significantly reduces the risk of scale or solids formation in the scrubber and thereby ensures high operational reliability.

Both of the internal scrubber configurations described in earlier paragraphs have been operated satisfactorily on industrial waste incinerators. Packed bed scrubbers are installed at:

- o HIM, Biebesheim, West Germany, operating since 1982 (Ref: Scharsach[17]), and
- o SCA Chemical Services, Chicago, USA, operating since 1983 (Ref: Gorman et. al.[27]).

Open spray chamber (radial type) scrubbers are installed at:

- o GSB, Ebenhausen, Bavaria, West Germany, operating since 1976 (Ref: The Proctor & Redfern Group[24]), and
- o BASF, Ludwigshafen, West Germany, operating since 1978 (Ref: Brenner et. al.[26]).

Contaminants are removed from the wet scrubber by bleeding off a portion of the recirculating scrubber water as a liquid effluent. The liquid effluent would require subsequent physical/chemical treatment prior to reuse, discharge, or disposal.

Clean flue gases pass through demisters, for the removal of water droplets, prior to being reheated to 130°C in steam/flue gas heat exchangers.

The gases are then discharged to atmosphere via an induced draft fan and a stack. The induced draft fan inlet control vanes modulate to maintain a slight negative pressure in the rotary kiln, thereby avoiding pressurization and consequential leakage of untreated combustion gases to the atmosphere.

Alternative 2

The incineration system for Alternative 2 is similar to Alternative 1, except that the waste heat recovery boiler is of a convective design. Air injection, otherwise known as air attemporation, is used to cool the raw flue gases from 1250°C to about 800°C prior to them entering the boiler heating surfaces, as illustrated on Figure 2.

The convective boiler type included in Alternative 2 is well proven at the following installations:

- o Kommunekemi, Nyborg, Denmark, operating since 1976 (Ref: Kristensen[28])
- o HIM, Biebesheim, West Germany, operating since 1982 (Ref: Scharsach[17])
- o SAKAB, Norrtorp, Sweden, operating since 1983

Various designers and operators of industrial waste incineration processes hold widely differing views on the type of waste heat recovery boiler best suited for this application.

Some companies prefer totally radiant boiler designs where flue gases enter the boiler from the incinerator secondary combustion chamber at temperatures ranging from 1100°C to 1250°C, and are cooled by passage between widely spaced welded water cooled tube panels (platens) in a vertical multi-pass configuration. Such boilers employ a combination of luminous and non-luminous radiation and to a lesser extent, convective heat

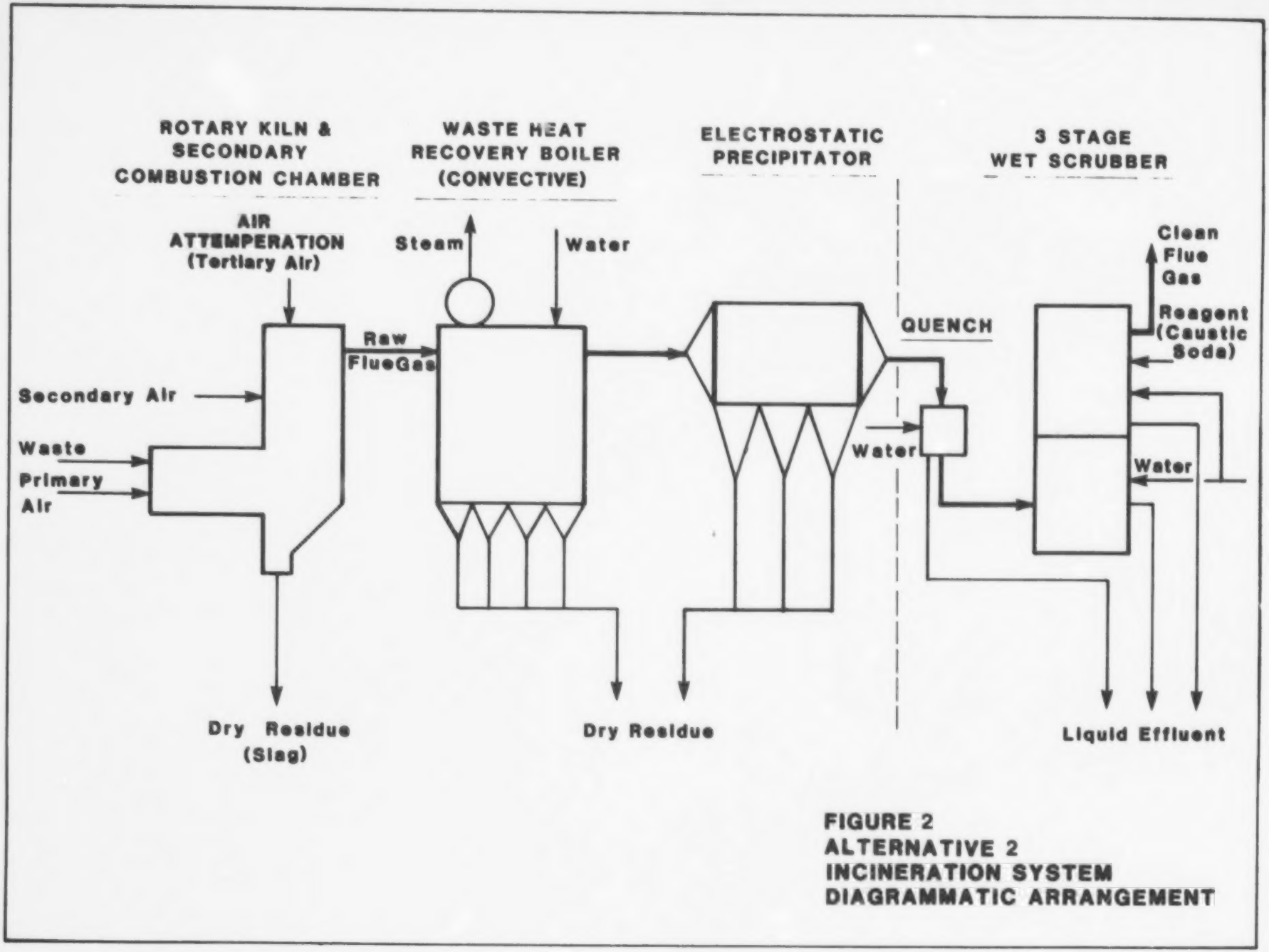


FIGURE 2
ALTERNATIVE 2
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

transfer. These designs are physically large and relatively expensive to construct, but are conventionally applied to high temperature heat recovery applications involving heavily dust laden flue gases.

Advocates of such boiler designs claim that these units can tolerate high dust loading without concern for plugging of gas passes although on-line cleaning of boiler surfaces is an acknowledged problem and it is not unusual for units to be shut down at 3 - 4 month intervals for internal cleaning.

Other companies prefer a more economic boiler design comprising one or two radiant heat transfer passes to cool the flue gas to about 800°C, following which conventional convective heat transfer surfaces are employed to efficiently reduce the flue gas temperature to the desired outlet value. Critics of such designs claim that tubeside fouling in the radiation chambers will ultimately lead to a rise in the flue gas temperature at the inlet to the convective section, with consequential deposition in this section due to the gas temperature exceeding the fusion temperature of ash particles. This type of boiler design has the same characteristics as a radiant boiler from a process perspective, and the term "radiant boiler" is used in this report to describe both types.

The third approach is for a totally convective boiler design involving vertical tubes arranged in a single horizontal gas path. Tubes are cleaned automatically by a mechanical rapping system. However, flue gases leaving the secondary combustion chamber of the incinerator must be cooled by air addition to about 800°C prior to them entering the boiler, in order to avoid the tubeside fouling phenomena described earlier. The heat transfer in a boiler of this design is predominantly convective with a relatively small radiant component, and this boiler type is therefore referred to as a "convective boiler" for convenience in this report.

Von Roll believe that in their experience with all three types of boilers described, the latter design provides greater overall reliability in service. They specifically claim that the design:

- o permits full control over the temperature of flue gas entering the unit and thereby eliminates fouling from fused deposits,
- o includes a highly effective tube cleaning device,
- o minimizes tube erosion by avoiding changes in gas direction, and
- o results in increased on-line availability i.e more operating hours/year.

Critics of this boiler design correctly point out that the injection of cooling air results in a reduction of boiler efficiency and a substantial increase in the quantity of flue gas to be handled in downstream flue gas treatment systems. Advocates of the design counter that such considerations are of secondary importance to high system on-line availability i.e. a high number of operational hours/year during which the system is available to treat waste. When comparing preliminary process designs for this evaluation, the steam quantity generated in Alternative 2 is reduced by approximately 15% and the flue gas quantity requiring treatment is increased by about 45% when compared to Alternative 1.

Comparison of the techno-economic-environmental characteristics of system designs represented by Alternatives 1 and 2 permitted OWMC to determine whether there was any significant difference between the two concepts which should be taken into consideration in their selection of Incineration Technology Consultant, and in the design of OWMC's Facility. Discussion of this comparison is given in Section 3.6.3 (p. 81).

Alternative 3

The incineration system for Alternative 3 consists of a rotary kiln incinerator, controlled evaporative water cooling of flue gas, an electrostatic precipitator and a three stage wet scrubber arranged in series. Hence, the major difference from Alternative 1 is that evaporative water cooling is used to reduce the flue gas temperature in lieu of a waste heat recovery boiler.

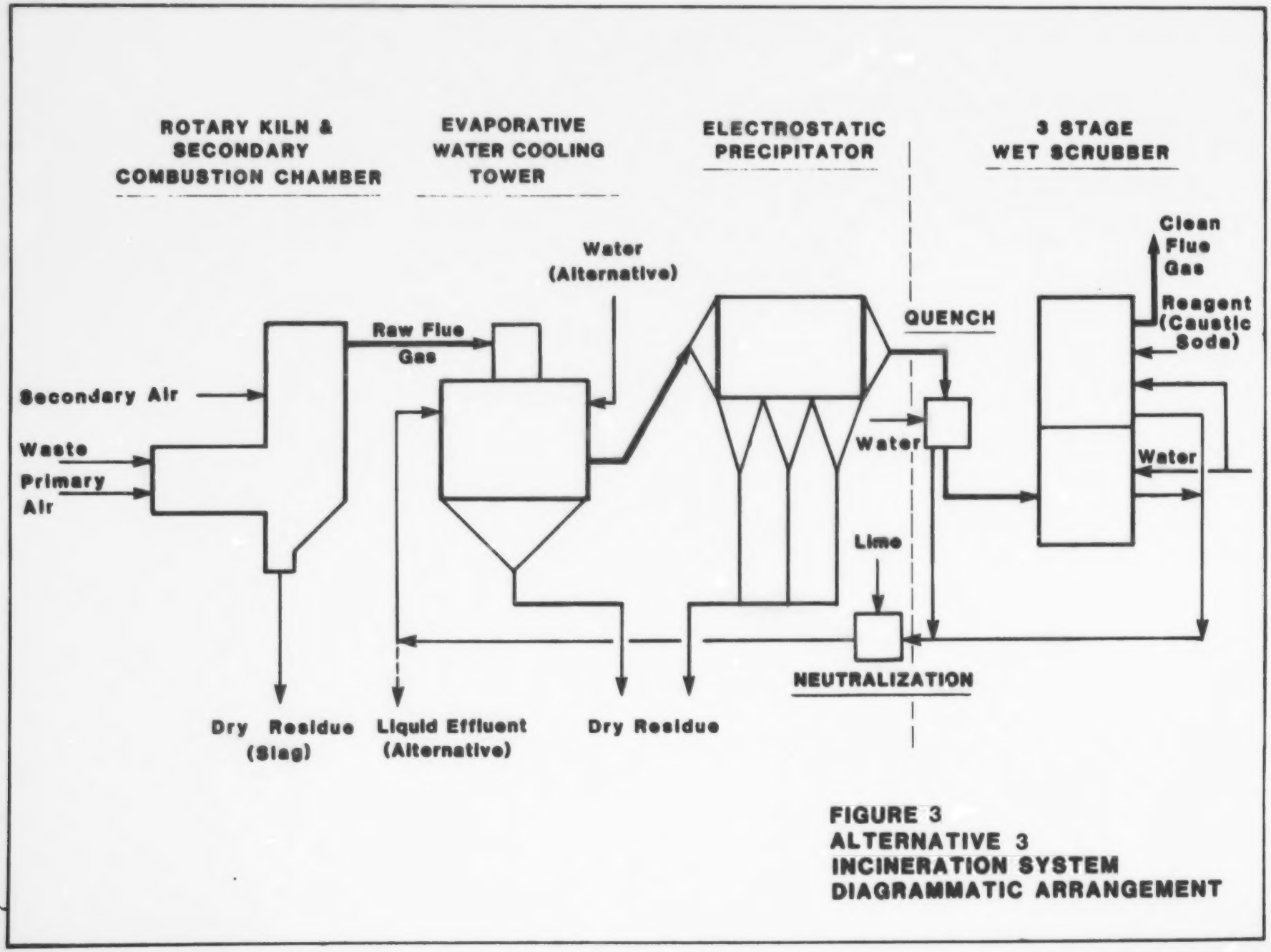


FIGURE 3
ALTERNATIVE 3
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

This alternative was selected for direct comparison with Alternative 1 and to thereby determine whether heat recovery is justified at OWMC's Facility.

Most of the modern industrial incinerator installations in Europe incorporate heat recovery and there are few examples where evaporative cooling has been utilized. However, there are many municipal garbage incinerators operating in Europe, particularly in the United Kingdom (Ref: Watson et. al.[30], Whithead et. al.[31]), which use controlled evaporative water cooling in conjunction with flue gas treatment systems employing electrostatic precipitators. Hence, the conceptual design is well proven on incineration systems, but to a lesser extent on industrial waste incineration systems.

An industrial waste incineration plant equipped with controlled evaporative water cooling is installed at:

- Ford-Werke AG, Köln, West Germany, operating since 1968. (Ref: VKW[29])

This facility includes a rotary kiln incinerator, evaporative water cooling tower and an electrostatic precipitator.

On the other hand, there are many uncontrolled evaporative water cooling systems operating in the USA on industrial waste incineration plants. The difference here, is that flue gases are quenched to saturation temperature (approximately 60°C) prior to them entering a wet scrubbing system, whereas for Alternative 3, a controlled amount of water is introduced to maintain a temperature of about 250°C at the inlet of the electrostatic precipitator.

Industrial waste incineration installations equipped with uncontrolled evaporative water cooling systems include the following:

- Eastman Kodak, Rochester, New York, USA, operating since 1976. (Ref: Bastian et. al.[32])

- SCA Chemical Services, Chicago, USA, operating since 1983. (Ref: Gorman et. al.[27])

The conceptual incineration system design represented by Alternative 3, was therefore considered reasonable for the purpose of comparison with Alternative 1, in determining the relative merits of systems with and without heat recovery. For this reason, it was not considered necessary to develop a further alternative system design incorporating uncontrolled evaporative water cooling although this is considered in Section 3.7.2 (pg. 97), as a sensitivity analysis. It was recognized that more detailed consideration would need to be given to the type of evaporative water cooling system employed, should this evaluation determine that heat recovery was not justified for OWMC's Facility.

While the flue gas treatment system for this alternative is unchanged from Alternatives 1 and 2, the quantity of flue gas requiring treatment is some 50% greater than for Alternative 1, due to the addition of large quantities of water.

It should also be noted from Figure 3, that two options can be considered for the disposal of liquid effluent from the wet scrubber. The effluent could be disposed of in the evaporative cooling system or sent to the physical/chemical treatment plant at the Facility for treatment. Both options were considered in this evaluation and are discussed in Section 3.6.3 (pg. 77).

Mist eliminators, an induced draft fan and flue gas reheating is provided as described earlier for Alternative 1.

Alternative 4

The incineration system for Alternative 4 is modelled after the facility at HIM Biebesheim, West Germany (Ref: Scharsach[17]) which has been operating since 1982, but with a number of distinct changes which will be elaborated upon later (pg. 65). The system is illustrated on Figure 4.

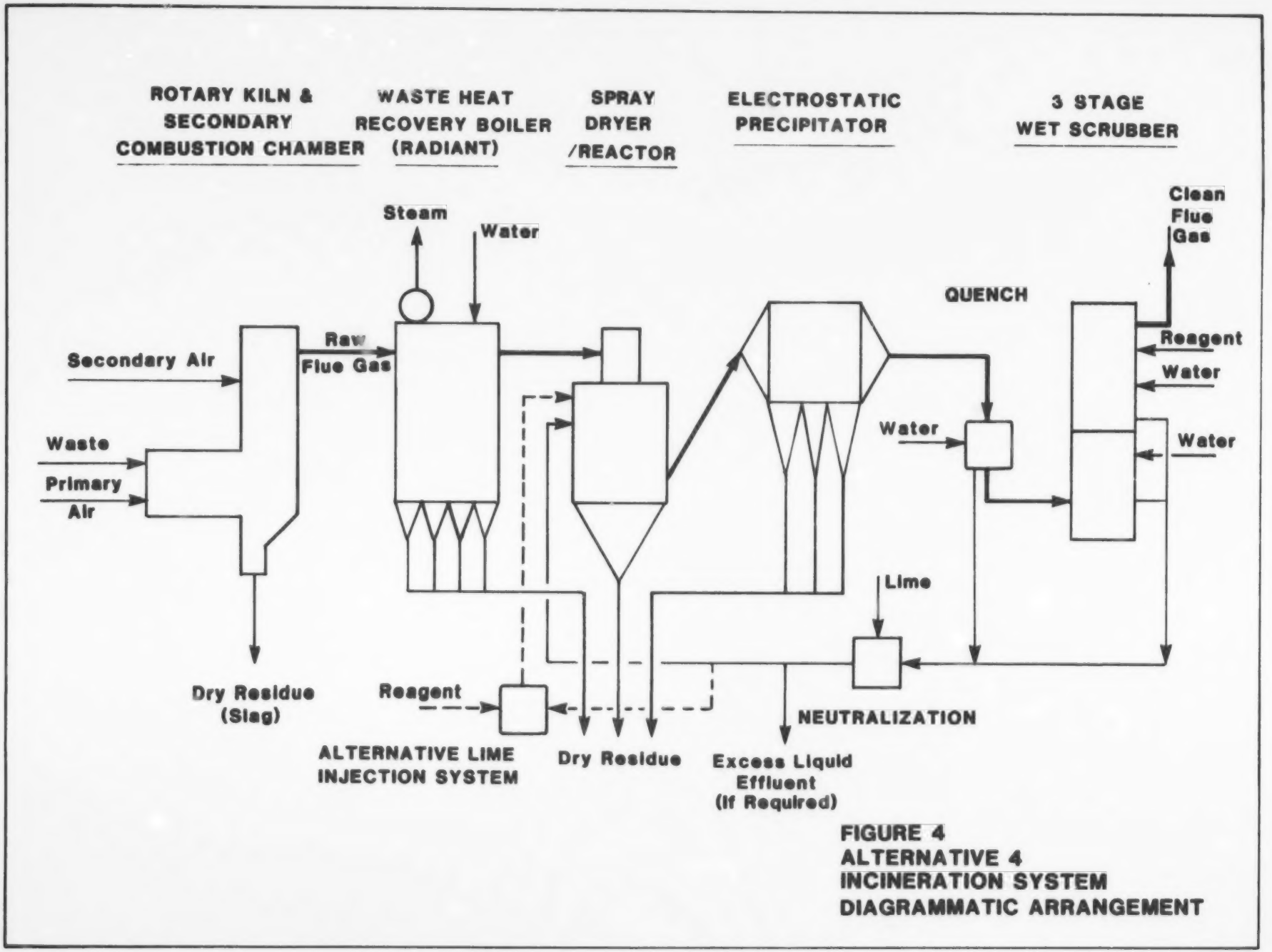


FIGURE 4
ALTERNATIVE 4
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

Raw flue gas is cooled in a radiant waste heat recovery boiler from 1250°C down to about 520°C, which is a significantly higher boiler outlet temperature than for Alternative 1 and results in reduced steam production (30% reduction). The reduced steam production is directly proportional to the reduction in the thermal energy extracted from the flue gas, which is a function of the flue gas inlet and outlet temperatures. The purpose of this higher temperature is to leave sufficient heat in the flue Insert gas to dispose of a portion, if not all, of the liquid effluent from the wet scrubber by evaporation in a spray dryer.

Liquid effluent from the wet scrubber is introduced to the spray dryer reactor through spray nozzles or by means of a rotating mechanical atomizer. The water is evaporated and in doing so cools the flue gas to 180°C at the outlet of the spray dryer. This temperature was selected to reduce the opportunity for corrosion in the electrostatic precipitator. The dissolved solids in the scrubber effluent are entrained in the flue gas as solid particulate material and removed as a dry residue in the electrostatic precipitator.

Flue gases are further treated for the removal of acid gases and fine particulates, including heavy metals, in a three stage wet scrubber as described for Alternative 1.

The main differences between this conceptual design and the HIM, Biebesheim installation are as follows:

- A radiant boiler design is included whereas at HIM Biebesheim, a convective design is installed.

- An electrostatic precipitator is included whereas two mechanical cyclones are used at HIM Biebesheim for the removal of particulate material entrained in the flue gas discharged from the spray dryer.

The change in boiler type influences the total quantity of gas to be treated in the flue gas treatment system, as previously explained in Alternative 2 (pg. 57), and also the thermal capacity of the spray dryer as

discussed further in this Section. The use of an electrostatic precipitator for the removal of particulates is seen as a natural development in the system concept, since it provides enhanced capability in the removal of contaminants.

Contaminants removed from the system in the solid dry residue, will be as inorganic particulates, soluble salts such as sodium chloride, sodium sulphate and calcium chloride, plus oxides of various heavy metals.

A further difference results from the significantly higher quantities of chlorine and sulphur anticipated in the waste, compared with that experienced at HIM. While most of the scrubber blowdown can be disposed of in the spray dryer at waste chlorine and sulphur contents of 5% and 1% respectively, the quantity of scrubber effluent resulting from the incineration of wastes having higher chlorine and sulphur content, up to 15% and 3% maximum respectively at OWMC's Facility, would be far beyond the evaporative capacity of the spray dryer, necessitating the discharge of excess liquid effluent for treatment at the physical/chemical treatment plant.

However, a number of opportunities were identified to avoid the necessity of discharging excess liquid effluent for treatment when incinerating waste having high chlorine and sulphur content. These are noted below:

- A convective waste heat boiler type could be used, thereby increasing the thermal capacity of the spray dryer for the same gas temperature entering the dryer, due to the larger gas flow.

- The scrubber could possibly be operated at higher concentrations of total dissolved solids, thereby reducing the quantity of liquid effluent to be disposed.

- A reagent such as caustic soda or lime could be introduced with scrubber blowdown into the spray dryer to react with some of the

acid gases and facilitate their removal as a dry residue in the electrostatic precipitator. This semi-dry scrubbing concept is further described in Alternative 8. In this manner, a two stage scrubbing system would be created and the reduced load imposed on the wet scrubber would significantly diminish the quantity of liquid effluent to be disposed (Ref: Barter[33]).

Sufficient opportunities were considered to exist for the optimization of this proven system concept to avoid the discharge of any liquid effluent under most operating conditions. Hence, Alternative 4 was confirmed as a viable option having the benefits of a wet scrubber, but without any discharge of liquid effluent, as demonstrated at the HIM Incineration Plant at Biebesheim, West Germany.

The last option identified above, involving two stage scrubbing, was adopted for evaluation purposes since it avoided changing the basic framework and assumptions established for the comparative assessment of alternative incineration systems. It also provided an opportunity for reducing reagent (operating) costs.

Mist eliminators, an induced draft fan and flue gas reheating is provided as described for Alternative 1.

Alternative 5

The incineration system for Alternative 5 consists of a rotary kiln incinerator, a radiant waste heat recovery boiler and a three stage wet scrubber arranged in series, as illustrated on Figure 5.

This conceptual system design is similar to that installed at:

- o BASF, Ludwigshafen, West Germany, operating since 1978. (Ref: Brenner et. al.[26])

Another example of this conceptual arrangement (employing another proprietary scrubber design) is installed at:

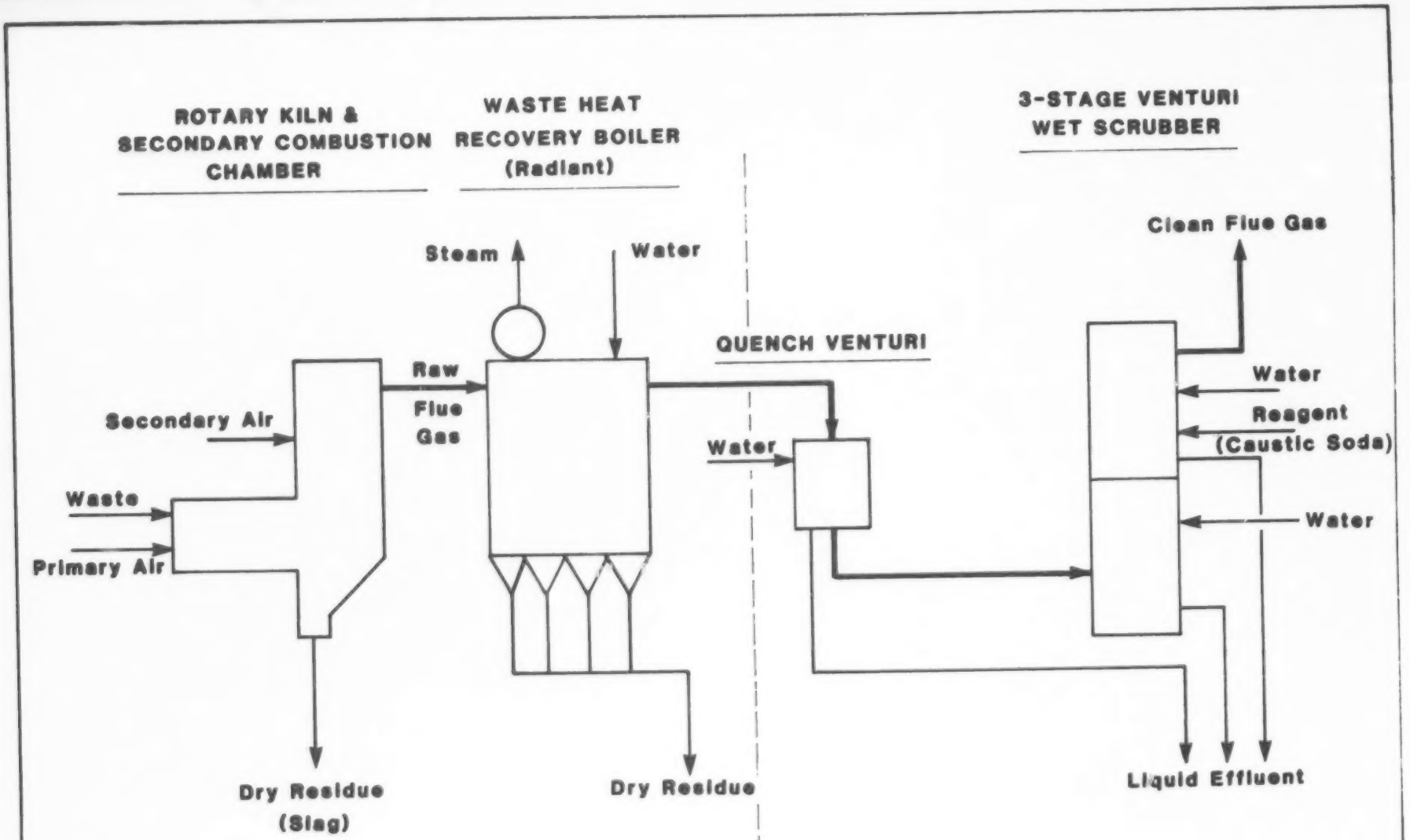


FIGURE 5
ALTERNATIVE 5
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

- Texas Eastman Company, Longview, Texas, USA, operating since 1984. (Ref: Acurex[34])

Incineration and flue gas cooling components of this alternative are identical to those previously described for Alternative 1.

Gases enter the first stage of the wet scrubber at a temperature of about 250°C and are quenched to a saturation temperature of about 60°C in a variable throat venturi scrubber, which also provides for the removal of particulate material from the flue gas.

The particulate material, which represents less than 1% of the liquid effluent, is discharged with the effluent to the physical/chemical treatment plant. The remainder of the wet scrubber system is similar to that described for Alternative 1.

It should be noted that the quantity of steam produced, the quantity of liquid effluent and the amount of flue gas discharged to atmosphere are all the same as for Alternative 1. However, the particulate loading within the scrubber, and potentially in the cleaned flue gas, is greater than for previous alternatives, as further discussed in Section 3.6.3 (pg. 77).

Mist eliminators, an induced draft fan and gas reheating is provided as described for Alternative 1.

Alternative 6

The incineration system for Alternative 6 consists of a rotary kiln incinerator, a radiant waste heat recovery boiler, a two-stage wet scrubber and an electrostatically augmented scrubber, as illustrated in Figure 6.

This conceptual system design is similar to that installed at the following industrial waste incineration facilities (Ref: Ceilcote[35]) employing rotary kilns, although few of these installations are understood to include heat recovery.

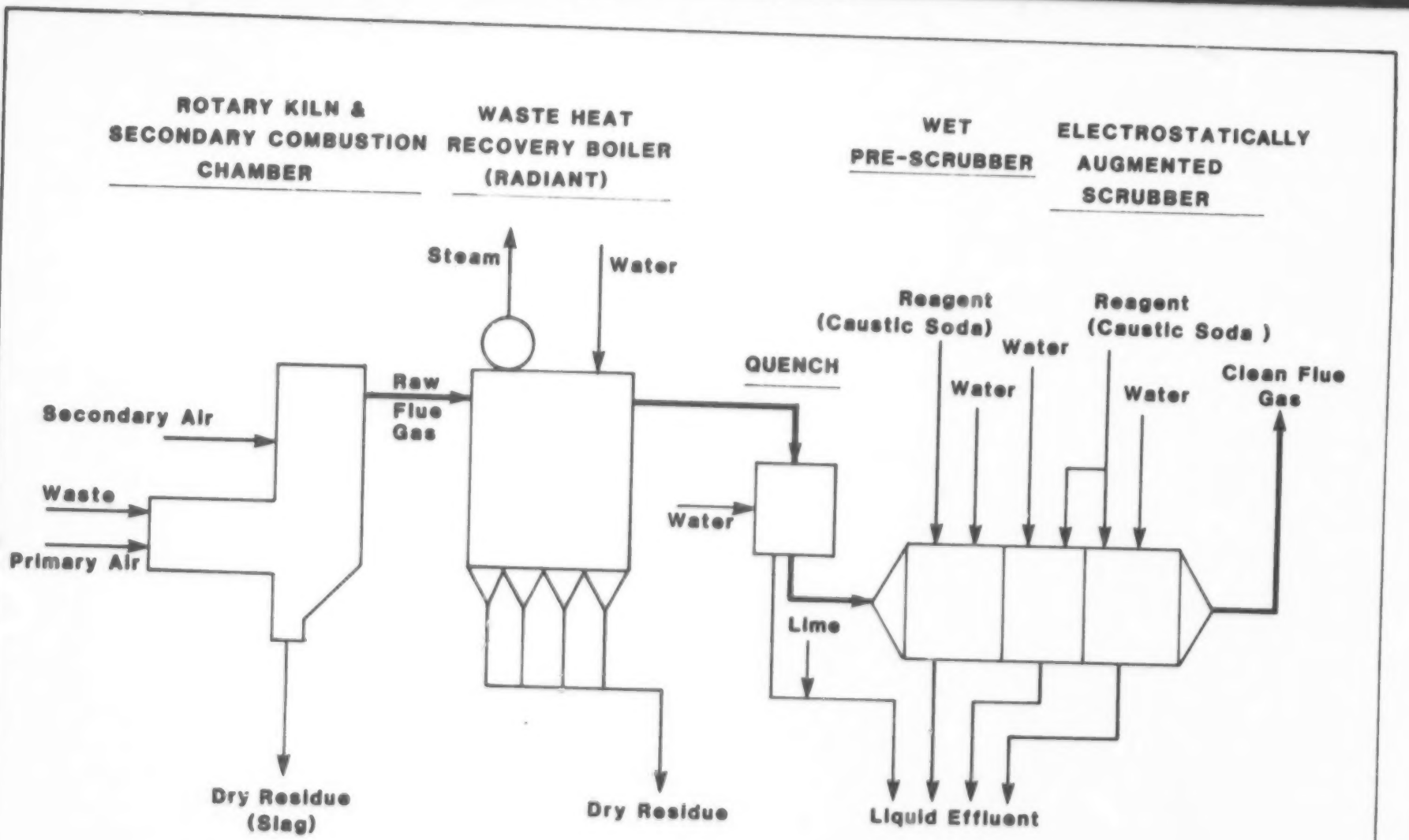


FIGURE 6
ALTERNATIVE 6
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

- General Electric Company, Waterford, New York, USA, operating since 1981.
- Rollins Environmental Services, Baton Rouge, Louisiana, USA, operating since 1981.
- SCA Environmental Services, Chicago, USA, operating since 1983.

Flue gases leave the waste heat recovery boiler at 250°C and pass directly to the wet scrubber system comprising the following:

- A quench section where gases are cooled to about 60°C by a deluge water system. This section also removes some coarse particulate material and some hydrogen chloride.

- A pre-scrubber section arranged for horizontal gas flow and containing a bed of irrigated packing followed by a bed of non-irrigated packing for liquid entrainment separation. The purpose of this pre-scrubber is to remove large liquid and solid particles remaining after the quench section, and also to provide initial gas scrubbing for the removal of hydrogen chloride (HCl) and sulphur dioxide (SO_2). A caustic soda solution is used as the recirculating reagent in the pre-scrubber.

- Two stages of electrostatically augmented scrubber modules follow the pre-scrubber. Each module consists of an ionizing section to electrically charge the particles in the gas stream before entering a packed bed section. The particulate material is attracted to the packing and removed with the irrigation water, which flows vertically down through the packing. Non-irrigated packing is again provided for mist separation. Caustic soda solution is used as the recirculating reagent for final treatment. Some designs of electrostatically augmented scrubber differ in detail to that described.

This system combines the principles of electrostatic precipitation and wet scrubbers. Electrostatically augmented scrubbers are noted for their efficiency in removing sub-micron particulates and as such provide an effective means of removing heavy metals, including aerosols produced as the flue gases are cooled.

The limitations on permissable total solids content in the scrubber liquid, combined with the four discrete water circuits, result in a larger quantity of liquid effluent than is required for Case 1. (Approximately 30% higher based on information received). The influence of this characteristic on system evaluation is discussed in Section 3.6.3 (pg. 89).

An induced draft fan and gas reheater are provided as for other alternatives.

Alternative 7

The incineration system for Alternative 7 consists of a rotary kiln incinerator, a radiant waste heat recovery boiler, a two stage wet scrubber and a wet electrostatic precipitator arranged in series, as illustrated on Figure 7.

Wet electrostatic precipitators have been installed at the following industrial waste incineration facilities (Ref: Dresser[36]), although we are unfamiliar with the specific incineration and pre-scrubbing system type, and whether heat recovery is employed at these facilities.

- Dow Chemical, Midland, Michigan, USA, operating since 1980.
- 3M Company, Cottage Grove, Minnesota, USA, operating since 1981.
- FMC, Baltimore, Maryland, USA, operating since 1983.
- Dow Chemical, Midland, Michigan, USA, operating since 1982.

Flue gases leave the waste heat recovery boiler at 250°C and pass directly to the wet scrubber system comprising the following:

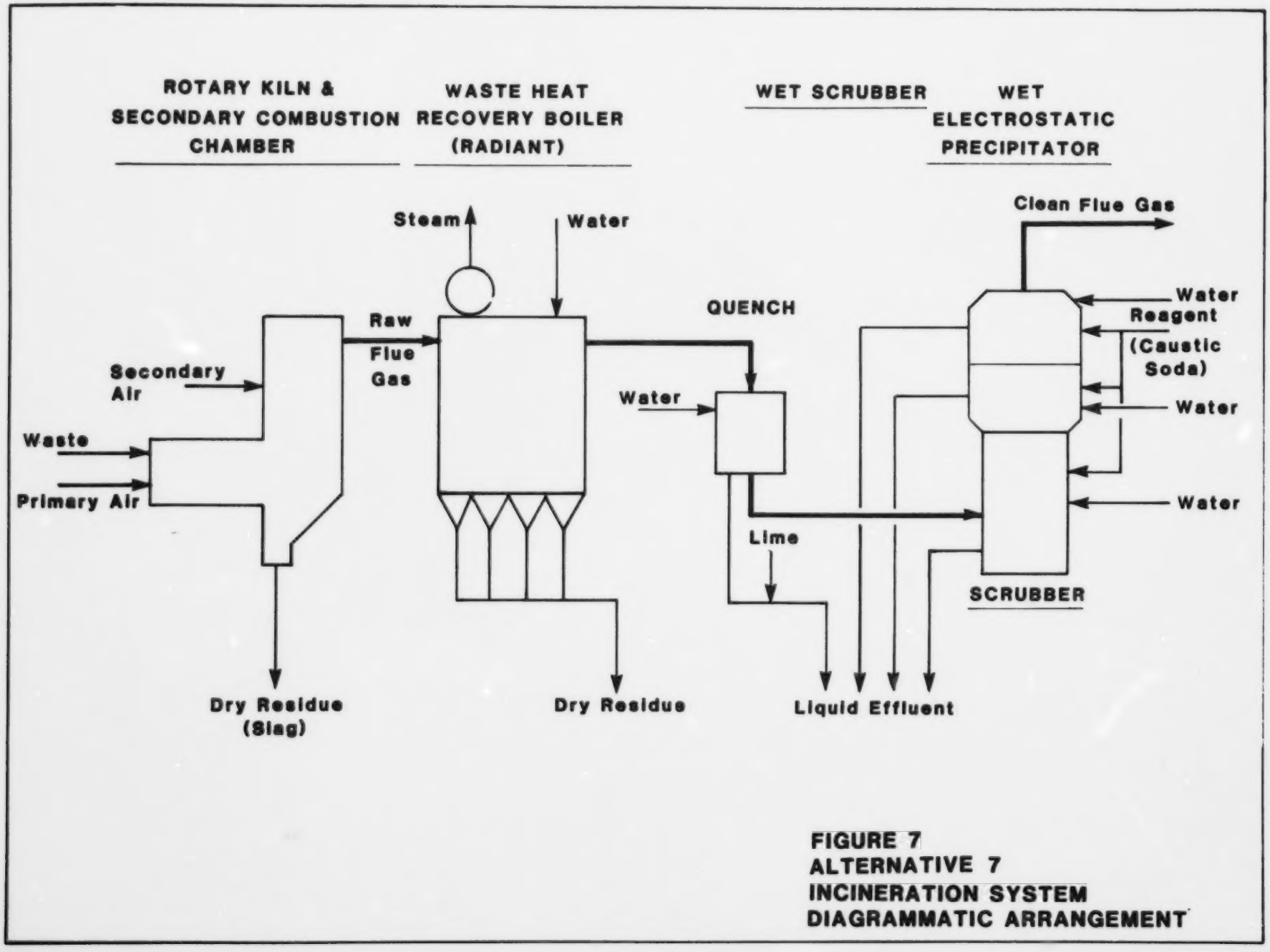


FIGURE 7
ALTERNATIVE 7
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

- o A quench section where gases are cooled to about 60°C by a deluge water system. This section also removes coarse particulates and some hydrogen chloride.

- o A packed bed scrubber section arranged in a vertical gas flow configuration, where caustic soda solution is used to remove hydrogen chloride (HCl) and sulphur dioxide (SO_2) from the flue gases.

- o Two stages of wet electrostatic precipitator follow the scrubber section and are designed to further reduce particulate material and acid gases remaining in the flue gas. The dust particles are charged by rigid frame discharge electrodes and attracted to the collecting plates which are continuously irrigated by a film of caustic soda solution.

Wet electrostatic precipitators are claimed to be highly efficient in the removal of sub-micron particulates including aerosols. The stages of flue gas treatment are conceptually similar to Alternative 6 and it might be expected that the quantity of liquid effluent discharged from the system would be similar for both Alternatives. However, the quantity of liquid effluent provided by the process suppliers is similar to that for Alternative 1.

An induced draft fan and gas reheater is provided as for other alternatives.

Alternative 8

The incineration system for Alternative 8, the final alternative considered, consists of a rotary kiln incinerator, a radiant waste heat recovery boiler and a semi-dry scrubbing system comprising a spray dryer/reactor and a fabric filter. An electrostatic precipitator was also considered in lieu of the fabric filter and this is discussed further in Section 3.6.3 pg. 93. The incineration system is illustrated on Figure 8.

A similar rotary kiln incineration system is installed at:

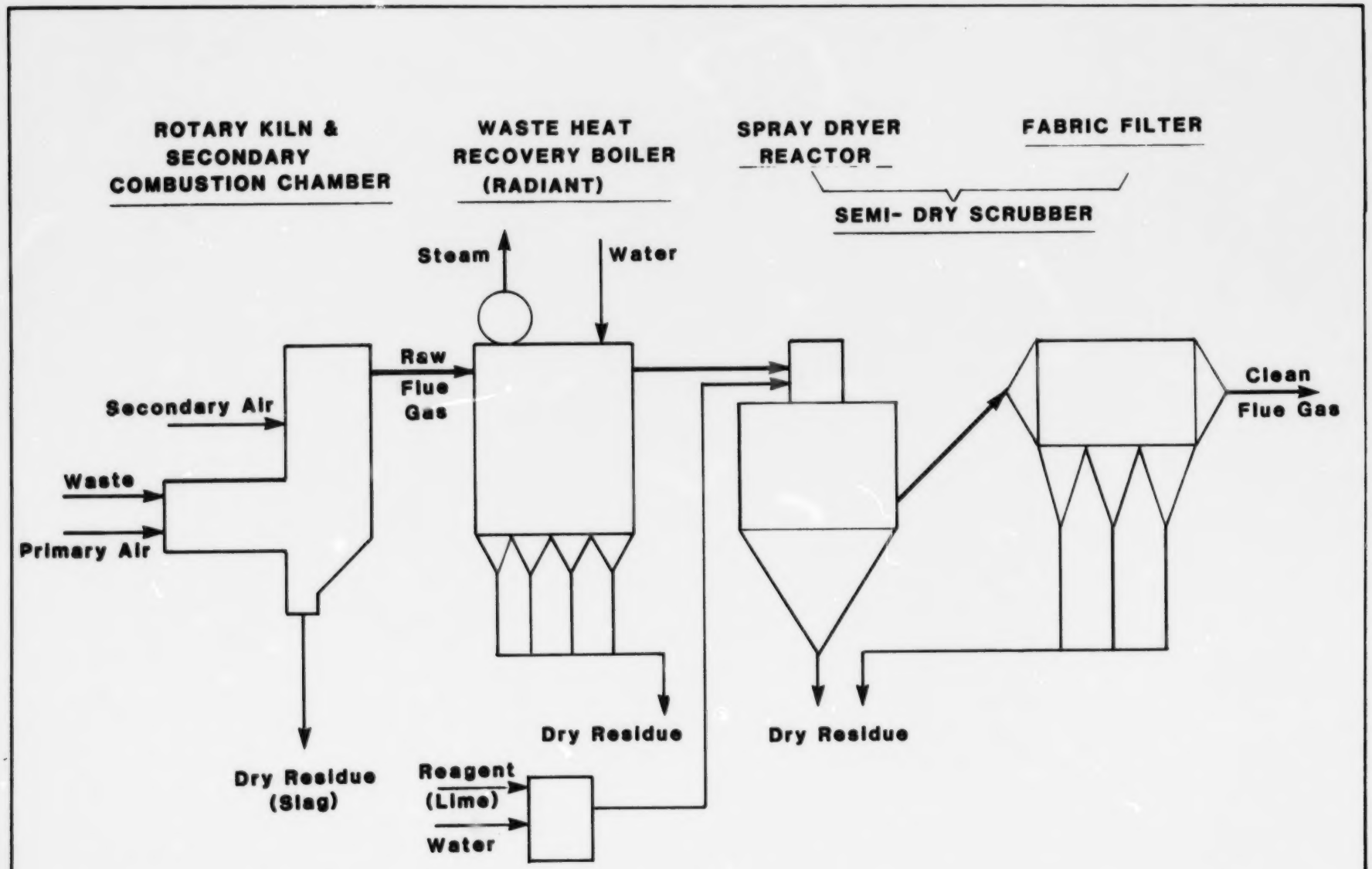


FIGURE 8
ALTERNATIVE 8
INCINERATION SYSTEM
DIAGRAMMATIC ARRANGEMENT

- Ekokem OY Ab, (formerly Suomen Ongelmajate OY), Riihimäki, Finland, operating since 1984.
  (Ref: Orkild[37], Moller et. al.[38])

Similar incineration systems of this type, but with an electrostatic precipitator in lieu of the fabric filter, are installed at the following facilities:

- Kommunekemi, Nyborg, Denmark, operating since 1982.
  (Ref: Kristensen[28], Orkild[37])
- SAKAB, Norrtorp, Sweden, operating since 1983.
  (Ref: The Proctor & Redfern Group[24], Orkild[37], Moller et. al.[38])

The specific boiler designs on these installations are not necessarily of the radiant type, as discussed earlier (pg. 57).

In addition, the liquid injection incineration system of Tricil Limited, Sarnia, Ontario is equipped with a semi-dry scrubbing system operating in conjunction with an indirect gas/air tubular heat exchanger, which provides gas cooling (Ref: Redhead[23]).

In this alternative, flue gas leaves the heat recovery boiler at a temperature of 525°C, similar to that for Alternative 4, with a consequential reduction in steam generation of some 30% compared with Alternative 1.

The temperature of 525°C at the inlet to the spray dryer/reactor was selected to maximize the thermal evaporative capacity of the spray dryer/reactor without exceeding the temperature limitations of rotary mechanical atomizing equipment. Experience on industrial incinerators has been almost exclusively with atomizers of this type. Lime slurry is sprayed into the spray dryer/reactor and reduces the flue gas temperature to 180°C at the outlet of the unit. This temperature was also selected to maximize thermal capacity of the spray dryer/reactor but maintained sufficiently high to reduce concerns of low temperature corrosion which might otherwise occur in the fabric filter.

Installations of semi-dry scrubbing systems operating in Finland, Denmark and Sweden operate with temperatures of approximately 250°C and 140°C at the inlet and outlet of the spray dryer/reactor respectively. The higher temperatures proposed for Alternative 8 result directly from the significantly higher hydrogen chloride and sulphur dioxide concentrations in the raw flue gas, as further discussed in 3.6.3, pg. 93.

Reagent combines with acid gases to form solid salts which are then removed from the flue gas along with flyash, in the fabric filter.

Various proprietary designs of fabric filter exist, however the basic concept is similar for most types. Flue gas enters the fabric filter unit which contains a multitude of fabric filter tubes supported vertically by structural frames. Gases pass through the fabric filter tubes and discharge from the top into a gas plenum chamber. Clean flue gas is discharged from the unit via the plenum chamber. Particulate material is retained on the outside surface of the filter tubes, and is periodically removed by a variety of different techniques which include mechanical shakers, reversal of gas flow and pulses of compressed air into individual bags. The dislodged particulate material falls into hoppers situated beneath the fabric filter unit from where it is removed.

Semi-dry scrubber systems equipped with fabric filters are considered excellent for the removal of heavy metals, since fabric filters are extremely effective in the removal of particulates, including those in the sub-micron size range.

Reacted flue gas contaminants are removed from the spray dryer/reactor and fabric filter as a dry residue. Cleaned flue gases are discharged from the system at a temperature of 180°C via an induced draft fan, without any requirement for reheating prior to being discharged to atmosphere.

3.6.3 ASSESSMENT OF ALTERNATIVES

The relative suitability of the alternative rotary kiln incineration systems described in Section 3.6.2 has been examined to determine which is best suited for OWMC's treatment Facility. The following assessment is

based on the technology evaluation criteria described in Section 3.3 (pg. 17), with particular emphasis on those dealing with protection of human health and the environment. The assessment will focus on aspects which differ between the eight alternatives considered.

Appendix A contains a numerical comparative evaluation of the various alternatives, using the criteria weighting factors identified in Section 3.3.8 (pg. 28). The numerical evaluation has been adopted to assist in the technology evaluation process although this does not eliminate the need for qualitative evaluation and engineering judgement in the selection of a preferred alternative, as previously explained at the end of Section 3.3.8 on page 31.

Alternative 1

This alternative consists of a rotary kiln incinerator, a radiant waste heat recovery boiler, an electrostatic precipitator and a three stage wet scrubber arranged in series as illustrated on Figure 1 and described on page 52.

The system is rated highly in terms of its performance, for the following reasons:

- o It is capable of meeting the flue gas quality objectives established for this evaluation, with potential for further improvement during design optimization.

- o It can be designed to remove heavy metal contaminants from the system in a highly efficient manner.

- o Use of a radiant boiler type minimizes the total gaseous discharge to atmosphere and thereby achieves the lowest thermal discharge from the stack.

- o Flyash is removed from the system as a dry material which can be subsequently treated by solidification in an optimum and efficient manner. This is important since the flyash will contain heavy metal contaminants.

- The system is extremely well proven on many similar installations.

These characteristics ensure that discharges to the environment can be minimized during normal operation and performance can be confidently predicted.

The quantities of reagent, power and water required by this alternative are generally median to the range experienced by all alternatives. Contaminants are discharged from the wet scrubber as a liquid effluent and this requires subsequent treatment in the physical/chemical treatment plant.

On-line manual cleaning of boiler heating surfaces is often required with radiant boilers, and this can be a concern with regard to personnel safety.

No special noise considerations distinguish this or any alternative from any of the other options.

The process system has a high tolerance for "upsets" resulting from operational errors, such as overloading the incinerator or excessive feeding of high chlorine containing waste. The ability of the electrostatic precipitator to accept high particulate loadings and of the wet scrubber to accept high acid gas concentrations, are major contributors to this capability. Under most upset or emergency shutdown conditions the flue gas treatment system will continue to operate in ensuring that flue gases are properly treated prior to being released to the environment. In the event of power failure, the waste heat recovery boiler continues to cool the flue gases and an emergency water supply to the scrubber enables it to continue scrubbing the gases, albeit at a reduced efficiency. Emergency power can restore full flue gas treatment capability within a minute of power failure.

Such features ensure that process upsets and emergency shutdowns are dealt with as safely as possible.

System flexibility is considered the highest of all alternatives in terms of its capability to respond to changes in waste characteristics and also in terms of process turndown. This ensures that the excellent performance of this system in minimizing contaminant discharges to the environment can be maintained over a wide range of operating conditions.

Items requiring greatest maintenance are likely to be the radiant type heat recovery boiler and the wet scrubber, excluding the combustion system itself which is common to all alternatives considered. The incineration system has five primary items, namely rotary kiln, secondary combustion chamber, heat recovery boiler, electrostatic precipitator, and wet scrubber. Failure of any of these items may result in a process upset and/or shutdown. However, the reliability of the system has been well demonstrated thereby providing assurance that the required performance in minimizing contaminant discharges to the environment can be consistently achieved.

The process system can be fully automated, with operator surveillance and no unusually complex operational considerations exist for this alternative.

From a cost viewpoint, Alternative 1 is ranked in a median position equal with Alternatives 2, 5 and 7. This median ranking is influenced by the high treatment and disposal costs associated with the liquid effluent discharged from the wet scrubber.

Overall, this alternative was ranked highly in terms of its ability in meeting OWMC's principal goals of minimizing risk to human health and impact upon the environment. The major deficiency of this alternative relates to its low ranking in terms of residue characteristics and high associated cost in the treatment and disposal of scrubber effluent.

Alternative 2

Alternative 2 consists of a rotary kiln incinerator, a convective waste heat recovery boiler, an electrostatic precipitator, and a three stage wet scrubber arranged in series as illustrated on Figure 2 and described on

page 57. The process scheme is identical to Alternative 1 except for the heat recovery boiler type.

The assessment of this alternative is similar to that for Alternative 1, and differs in the following respects:

- The use of air to cool the flue gases ahead of the waste heat recovery boiler increases the quantity of raw flue gas requiring treatment and ultimately being discharged to atmosphere by about 45%. While this large quantity of raw flue gas will contain the same quantity of contaminants as for Alternative 1, the lower contaminant concentrations are more difficult to remove. However, the process suppliers indicated that quantity of residual contaminants discharged to atmosphere for this alternative would be no greater than for Alternative 1, but it requires the use of larger, more costly equipment.

- The larger total gaseous discharge to atmosphere via the stack, also represents an increased thermal discharge to the environment, but not on an overall basis since for Alternative 1 the heat will be recovered by the "heat recovery boiler" and ultimately transported to the environment via other pathways eg. via a steam to air steam condenser, or by evaporating process effluent to atmosphere. A benefit of the larger gaseous discharge via the stack will result from increased buoyancy of the stack plume which will more efficiently disperse residual flue gas contaminants in the environment. Hence, none of the alternative process systems was penalized on account of the total quantity of flue gas discharged to atmosphere via the stack.

- No on-line manual boiler cleaning is necessary with the convective boiler type and the concern previously expressed for Alternative 1 regarding occupational safety, does not apply.

- The overall evaluated cost of this Alternative is the same as for Alternative 1, but the individual capital and operating cost

components differ. The lower cost of the convective heat recovery boiler is offset by a more costly flue gas treatment system resulting from the larger quantity of flue gas requiring treatment. Also, slightly higher operating costs and reduced heat recovery in the form of steam, are offset by the improved "availability", expressed as annual operating hours, which can be achieved from a convective type boiler.

Overall, this alternative was ranked slightly higher than Alternative 1 in terms of its ability to meet OWMC's principal goals of minimizing risk to human health and impact upon the environment, mainly due to the avoidance of manual on-line boiler cleaning and the associated risk to operators. However, opportunities exist to mitigate this risk and it was agreed with OWMC that the selection of heat recovery boiler type should be based on the recommendation of the Incineration Technology Consultant, in accordance with that consultants experience.

Alternative 3

This alternative consists of a rotary kiln incinerator, controlled evaporative water cooling of flue gas, an electrostatic precipitator and a three stage wet scrubber arranged in series as illustrated in Figure 3 and described starting on page 60. The process is similar to Alternative 1 except that an evaporative cooling tower replaces the waste heat recovery boiler.

An opportunity exists to dispose of liquid effluent from the wet scrubber by evaporation in the cooling tower, thereby producing a dry residue which is removed in the electrostatic precipitator. There are many examples of cooling towers of this type using fresh water or process effluent on a variety of municipal garbage incinerators and at least one industrial waste incineration plant.

Our assessment of this alternative differs in several respects from Alternative 1 as identified below. The performance of the incineration system differs from Alternative 1 in the following manner:

- The use of evaporative water cooling in lieu of a heat recovery boiler increases the quantity of raw flue gas requiring treatment and ultimately discharged to atmosphere, by about 50% over Alternative 1. However, as explained previously under Alternative 2 (p. 81) this is not considered a significant aspect in this evaluation.

- The flue gas treatment system will treat the flue gases equally well as for Alternative 1, hence the absolute quantity of residual contaminants discharged to atmosphere should also be no more than for the previous alternatives discussed (Alternatives 1 and 2).

- Some uncertainty exists on whether all of the scrubber effluent can be disposed of in the cooling tower without significant re-volatalization of certain compounts, including heavy metals, and consequential deterioration of the treated flue gas quality. A staged cooling system may be required in order to ensure that no deterioration of treated flue gas quality occurs, and this would in itself limit the amount of scrubber effluent which can be disposed of.

- Utility water requirements are greater for this alternative, although this may not be a major factor if final effluent from the physical/chemical plant is used for scrubber makeup water and/or for evaporative cooling of flue gases.

- Liquid effluent from the wet scrubber will either be sent to the physical/chemical treatment plant for treatment, or evaporated in the cooling system and the contaminants removed as a dry residue from the electrostatic precipitator. The latter situation permits concentrated residues to be treated by solidification in an optimum and efficient manner.

These differences, including the uncertainties mentioned, lead us to rank Alternative 3 somewhat poorer than Alternative 1 in its ability to minimize environmental discharges during normal operation.

The flexibility of this system in dealing with changes to waste composition is considered equal to Alternative 1, whereas the requirement for water spray atomizers in the cooling tower lead us to rank the systems flexibility in terms of process turndown capability marginally lower than for Alternative 1. The required performance in minimizing contaminant discharges to the environment should nevertheless be achieved over a wide range of operating conditions.

Overall maintenance requirements should be similar to Alternative 1, with the major maintenance items being the cooling tower and wet scrubber. This process sytem has the same number of functional components as Alternative 1 and is therefore judged equal to that alternative in its susceptability to breakdown and process upset.

The cooling tower would be provided with an emergency water supply to ensure continued operation in the event of power failure. This and other features described earlier for Alternative 1 would ensure that process upsets and emergency shutdowns can be dealt with in an environmentally safe manner.

Operational considerations are judged to be similar to other alternatives previously discussed.

The capital cost of this alternative is significantly lower than any other alternative considered, mainly due to the omission of a heat recovery boiler and associated support systems. The operating cost of this option is also lower than either of Alternatives 1 and 2 despite a significantly higher cost of fuel for facility heating purposes. However, this operating cost advantage is totally dependent on the ability to dispose of scrubber effluent in the cooling tower and without this feature, Alternative 3 would have one of the highest operating costs of any alternative considered.

A comparison of this alternative with Alternative 1, showed that the inclusion of heat recovery could be economically justified by a simple payback of about six years, where reliance cannot be placed on the cooling tower to dispose of scrubber effluent. However, heat recovery is not

economically justified if the cooling tower can be relied upon to dispose all of the scrubber effluent. Also, if a two stage cooling tower is required then the potential cost advantage of this alternative will diminish.

Overall, this alternative was ranked lower than either of the previous alternatives since the potentially more favourable economics were judged to be of secondary importance compared with those criteria dealing with performance and flexibility, which focus on OWMC's primary goals of minimizing risk to human health and impact on the environment. The alternative was penalized in the ranking due to uncertainty of whether all the scrubber effluent could be disposed of in the cooling tower. Considerable uncertainty also exists regarding the economic ranking of this alternative, as discussed above.

Alternative 4

This alternative consists of rotary kiln incinerator, a radiant waste heat recovery boiler, a spray dryer/reactor, an electrostatic precipitator and a three stage wet scrubber as illustrated on Figure 4 and described starting on page 63.

The system is rated higher than any other alternative in terms of its performance, for the following reasons:

- It is capable of meeting the flue gas quality objectives established for this evaluation, with potential for further improvement during design optimization.

- It can be designed to remove heavy metal contaminants from the flue gas in a highly efficient manner, as demonstrated by extensive testing of the system at HIM Biebesheim.

- Both flyash and all other gaseous contaminants are removed from the system as a dry residue in normal operation. Some excess effluent from the wet scrubber may have to be discharged to the physical/ chemical plant when incinerating waste having maximum chlorine and

sulphur content. The dry residue contains the contaminants in concentrated form thereby enabling these to be treated by solidification in an optimum and efficient manner.

- The basic concept of a "zero effluent" wet scrubbing system has been demonstrated at HIM Biebesheim and other applications on municipal refuse incineration plants.

- A combined dry/wet scrubbing arrangement was selected as one possible refinement of the proven system concept, and used as a basis for this evaluation. The dry/wet scrubbing arrangement was considered as an opportunity to expand the capability of the system in treating wastes having high chlorine and sulphur contents. One of the benefits of this arrangement is that some of the acid gases can be removed using a lower cost reagent such as lime, in lieu of caustic soda.

These characteristics ensure that discharges to the environment can be minimized during normal operation, thereby satisfying OWMC's primary goals in terms of human health and the environment.

System flexibility in dealing with wide ranges of waste composition are considered equal to the previous alternatives examined. However, the systems flexibility in terms of process turndown capability was considered marginally lower than Alternatives 1 and 2, due to the reduced evaporative capacity of the spray dryer which will occur at part load operation because of the lower flue gas outlet temperature from the waste heat recovery boiler. This latter point would not pose any operational constraint, since any excess liquid effluent would be discharged for treatment in the physical/chemical plant. The system is considered to have high overall flexibility in ensuring that its high performance capability in minimizing environmental discharges, can be achieved over a wide range of operating conditions.

The maintenance requirements of this system are likely to be higher than previous alternatives considered due to the larger number of process

components in the system, i.e. an additional item in the form of a spray dryer/reactor. The vulnerability of the system to breakdown is also higher than any of the options considered for the same reason.

However, this is not a major concern since the system has the same features previously described for other alternatives to ensure that it can be safely shut down in the event of process upset or breakdown.

The complexity of the process system is greater than for any other option. The process however can be fully automated with operator surveillance, and no unusually complex operational considerations exist.

Alternative 4 is more cost effective than any of the previous alternatives examined, despite its high initial capital cost, which is the highest of any alternative considered (see Appendix C). This high cost ranking results from relatively low residue treatment costs without any offsetting penalties such as those incurred by Alternative 3 for the non-recovery of waste heat.

Overall, this alternative was ranked higher than any of the options previously discussed since it best satisfies all three OWMC goals of minimizing risk to human health, impact upon the environment and cost.

Alternative 5

This alternative consists of a rotary kiln incinerator, a radiant waste heat recovery boiler and a three stage wet scrubber, including a venturi or similar system for the removal of particulates from the raw flue gas as illustrated on Figure 5 and described starting on page 67.

The system is ranked second lowest (poorest) of the alternatives considered, in terms of perform nce, for the following reasons:

- With the exception of Alternative 8, it is the only process system considered which relies solely on hydro-mechanical techniques for the removal of particulate material from the raw flue gas. While it may be possible to achieve the performance objectives

established for particulate material using this system, energy requirements will be extremely high and the potential for further improvement of performance by design optimization is limited. Most suppliers contacted indicated that they would not recommend such a system and could not guarantee that the minimum discharge objectives for particulates could be achieved without unusually high system pressure differentials and energy consumptions.

- Particulates, acid gases and heavy metals are removed from the flue gas by a wet system, and are discharged with the liquid effluent. Many of the heavy metals contained with particulates have the potential to dissolve in the scrubber water and this will place an additional burden on the physical/chemical plant in the treatment of scrubber effluent.

Not withstanding the above, this incineration system is well proven on several facilities in both Europe and the USA.

Systems of this type have good flexibility in dealing with changes to waste characteristics, with the exception of their potential susceptibility to fouling of the scrubber system when subjected to high raw gas particulate concentrations, unless particular care is taken in the design to counter such tendancies. This system is nevertheless ranked highly in terms of flexibility in maintaining its achievable performance over a wide range of operating conditions.

Maintenance requirements for Alternative 5 are the lowest of any alternative considered due to its fundamental simplicity. This also results in it having a relatively low susceptibility to breakdown, qualified only by the potential for fouling and errosive wear in scrubber circulating water systems, resulting from high particulate concentrations in the raw flue gas.

The system has a high tolerance for process upsets. The type of safety features described earlier for Alternative 1 (pg. 79) would equally apply for this alternative.

This alternative is the least complex of the flue gas treatment systems considered.

From a cost viewpoint, Alternative 5 is similar to Alternatives 1 and 2, mainly due to its lower capital cost. The high cost of scrubber effluent treatment results in it being ranked lower on cost than either of Alternatives 3 and 4.

Overall, Alternative 5 was ranked lower than any of the previous options examined, in terms of its ability to achieve OWMC's goals.

Alternative 6

This alternative consists of a rotary kiln incinerator, a radiant waste heat recovery boiler, a two-stage wet scrubber and an electrostatically augmented scrubber as illustrated on Figure 6 and described starting on page 69.

The system is rated quite highly on performance, since it has the ability to achieve the specific performance objectives established for this evaluation and has excellent potential for the removal of fine particulates and heavy metals. However, the overall performance assessment is tempered by the following:

- o While total reagent quantities are similar to other alternatives, a greater proportion of more costly caustic soda is used, based on information from vendors.

- o The quantity of scrubber effluent is approximately 30% greater than for any other wet scrubber concept considered, due to the need to maintain total solids concentrations within fairly low limits established by the process vendors.

- o Particulates, acid gases and heavy metals are all removed by a wet system and are discharged with the liquid effluent. This places an additional burden on the physical/chemical plant similar to that discussed for Alternative 5, when compared with options which remove particulates in a dry form ahead of the wet scrubber.

The system is nontheless well proven in several commercial facilities, although specific performance data on heavy metal removal was unobtainable. Overall, it was ranked closely behind Alternatives 1, 2 and 4 on performance in achieving OWMC's principal goals regarding human health and the environment.

System flexibility is good, limited only by the potential for fouling of the scrubber system, when subjected to high raw gas particulate concentrations.

Maintenance requirements for Alternative 6 are considered higher than for Alternatives 1 and 2 due to the inclusion of two wet scrubber components, i.e. packed bed pre-scrubber and the packed bed electrostatically augmented scrubber. The susceptibility to breakdown and process upsets is considered similar to Alternatives 1, 2 and 3 based on the number of process components.

The safety features described earlier equally apply to this alternative, thereby ensuring that proven upsets and emergency shutdowns can be dealt with in an environmentally safe manner without danger to operations personnel.

Process complexity of this system is considered similar to Alternative 1 and no unusually complex operational considerations are envisaged.

Alternative 6 is ranked lowest on a cost basis as a result of a fairly high capital cost, albeit less than Alternative 4, but more particularly due to the high cost of scrubber effluent treatment.

Overall Alternative 6 is ranked behind all previous alternatives considered in this evaluation, in meeting OWMC's goals of minimizing risk to human health, impact on the environment and cost.

Alternative 7

The process system for Alternative 7 consists of rotary kiln incinerator, a radiant waste heat recovery boiler, a two stage wet scrubber and a wet electrostatic precipitator arranged in series, as illustrated on Figure 7 and described starting on page 72.

In many respects the performance characteristics of this alternative should be similar to Alternative 6, particularly regarding its excellent potential for the removal of fine particulates including aerosols of heavy metals. However, the comparative assessment revealed several aspects of the design which differed from Alternative 7, as follows:

- The reagent requirements provided by process vendors were more consistent with those for other alternatives employing a wet scrubber.

- The quantity of scrubber effluent requiring treatment in the physical/chemical plant is similar to that for Alternative 1 and somewhat less than Alternative 6.

- Particulates, acid gases and heavy metals are all removed by a wet system and are discharged with the liquid effluent. The burden that this places on the physical/chemical treatment plant is similar to that previously discussed for Alternatives 5 and 6.

- While several wet electrostatic precipitators have been installed on incinerators, we have been unable to obtain details of the overall process system design, including type of incinerators used. For this reason rather more uncertainty exists than for previous alternatives, regarding the extent to which this type of process system has been successfully applied in similar commercial installations.

Again, difficulty was experienced in obtaining specific performance data on the capability of this type of system in the removal of heavy metals. This was a common problem experienced for any of the technologies

considered which had only been applied on privately owned facilities, as compared to the more open approach of government owned regional facilities.

Overall, from a performance perspective, this alternative was ranked below Alternative 6 in achieving OWMC's principal goals, mainly due to the limited information available on the extent of its use in similar installations.

Other system characteristics in terms of flexibility, reliability, safety and operational considerations were all assessed similarly to Alternative 6.

The capital and operating costs associated with Alternative 7 vary from Alternative 1 in only minor respects and on a cost basis Alternative 7 is ranked equal to Alternatives 1, 2 and 5, ahead of Alternative 6.

Overall, Alternative 7 is ranked equal to Alternative 6 with its advantage in terms of cost being offset by uncertainty regarding the extent to which it has been successfully demonstrated on similar facilities. The numerical ranking presented in Appendix A shows Alternative 7 slightly ahead of Alternative 6.

Alternative 8

This process system consists of a rotary kiln incinerator, a radiant waste heat recovery boiler and a semi-dry scrubbing system comprising a spray dryer/reactor and a fabric filter as illustrated on Figure 8 and described starting on page 74.

Alternative 8 has the distinction of being the only alternative considered which does not include a wet scrubber of some description for the removal of acid gases and fine particulate. Its' characteristics are extremely appealing at first sight due to the inherent simplicity, effectiveness in particulate removal, use of a low cost reagent (lime) and the dry residue produced. It also had good potential for removal of heavy metals and some organic compounds of concern (Ref: Moller[38]).

However, closer examination of the application of semi-dry scrubbing technology to OWMC's Facility reveals a number of concerns which influence our assessment of its performance.

It is often possible to achieve removal efficiencies better than 99% for hydrogen chloride (HCl) and 95% for SO_2 in semi-dry scrubber systems, depending upon inlet contaminant loadings, providing sufficient reagent can be introduced to the spray dryer reactor (Ref: Orkild[37]). At OWMC's proposed Facility however, the anticipated chlorine and sulphur concentrations in the waste will result in concentrations of HCl and SO_2 in the raw flue gas significantly greater than those which can be effectively dealt with by semi-dry scrubbing systems.

In this situation, the high acid gas inlet concentrations require quantities of reagents which exceed the amount which can be introduced to the spray dryer/reactor, despite the high inlet gas temperature, due to the limiting thermal capacity of the unit. Hence, the achievable ratios of reagent to contaminant at design conditions is much less than that required for optimum performance of semi-dry scrubbing systems and this results in a substantial reduction in performance.

The semi-dry scrubbing system cannot therefore even approach the performance objectives established as minimum requirements for this evaluation in the removal of acid gases from flue gases prior to them being released to atmosphere.

This process system is therefore ranked lowest of all alternatives considered, in its ability to achieve OWMC's principal goals of minimizing risk to human health and impact on the environment.

Another concern with this technology is the limited amount of information, which is only now becoming available, on the performance of fabric filters with industrial waste incineration systems of the type proposed by OWMC. The major concerns relate to the life expectancy of filter bags in an aggressive flue gas environment and the damage which can be caused to these bags due to high temperature excursions of the flue gas

(Ref: Power[39]). Most suppliers of these systems predict a filter bag life of less than three years and this leads to high maintenance/bag replacement costs. Such concerns are only heightened in the application of this technology on OWMC's incineration system, due to the high acid gas concentrations in the raw flue gases.

One would normally expect to achieve improved efficiency of sulphur dioxide (SO_2) removal in a system equipped with a fabric filter compared to an electrostatic precipitator, due to enhanced performance as flue gas passes through excess reagent which coats the filter cloths. No advantage is therefore forseen in considering an electrostatic precipitator as an alternative to a fabric filter for Alternative 8.

The flexibility of Alternative 8 is also considered to be the lowest of all alternatives since the evaporative capacity of the spray dryer reactor will reduce disproportionately at part load, due to the reduced heat recovery boiler outlet temperature, and thereby exacerbate the constrained performance characteristics previously discussed.

Our assessment of system reliability is quite favourable due to its inherent simplicity which offsets, to some extent, concerns regarding filter bag life expectancy and susceptability to temperature excursions.

This alternative is also ranked highly in terms of the protection provided to the environment during process upset and/or power failure, since the removal of particulates from the flue gas will continue unaffected by power failure, and some acid gas removal will also continue providing that a coat of reagent can be maintained on the filter cloths.

The capital cost of Alternative 8 is one of the lowest of all alternatives, and the operating cost is the lowest of all alternatives due to the low reagent costs and low residue treatment/disposal costs relative to other alternatives examined.

Overall, this alternative is ranked lowest of all the options considered despite its' many appealing features, due to its inability to meet the minimum performance objectives established for this evaluation in terms of acid gas removal. This alternative does not satisfy OWMC's principal goals of minimizing risk to human health and impact upon the environment.

3.7 SELECTION OF PREFERRED TECHNOLOGY

It should be recognized that this evaluation has been conducted on a project specific basis, and the conclusions may not necessarily apply to other project situations. Previous sections of this chapter describe alternative rotary kiln incineration process systems which have been examined as candidates for OWMC's Facility (Section 3.6.2, pg. 49) and assess those alternatives on a comparative basis (Section 3.6.3 pg. 77). This section summarizes the rationale for selection of a preferred alternative and then examines a number of options which could influence system design using a sensitivity analysis approach.

3.7.1 RATIONALE FOR SELECTION OF PREFERRED TECHNOLOGY

A recap of Section 3.6.3, pg. 77, will reveal that Alternative 4 is the preferred incineration process system. This alternative consists of a rotary kiln incinerator, a radiant waste heat recovery boiler, and a zero effluent flue gas treatment system comprising a spray dryer/reactor, an electrostatic precipitator and a three stage wet scrubber.

The comparative assessment of Alternatives 1 and 2 identified that the difference between an incineration system employing a radiant waste heat recovery boiler and one having a convective waste heat recovery boiler was relatively small. It was therefore considered that the final selection of boiler type should be based on the recommendations of OWMC's Incineration Technology Consultant, in accordance with that consultant's experience in

the design and operation of similar facilities. Both alternatives were therefore considered equal in subsequent comparisons with other process options.

Alternative 3, involving controlled evaporative cooling of flue gases, was ranked lower than Alternative 1 despite its potentially more favourable economics, since this was considered of secondary importance compared with the more favourable assessment of Alternative 1 against criteria dealing with performance and flexibility which focus on OWMC's primary goals of minimizing risk to human health and impact on the environment. The uncertainty of whether scrubber effluent can be reliably disposed of in a controlled evaporative cooling system was a significant factor in arriving at this decision.

While both Alternative 1 and Alternative 4 are ranked equally high in many respects, the elimination of a liquid scrubber effluent and the significantly more favourable economics of Alternative 4 draw us to conclude that this option best satisfies all three of OWMC's principal goals of minimizing risk to human health, impact on the environment and cost. The overriding advantage which this system holds over all others is its ability to combine the performance capabilities of wet scrubbers into an effluent-free process while still recovering useful energy, as steam, from the system.

Alternative 5, involving a three stage wet scrubbing system ranked lower than Alternative 4 in terms of its expected performance in minimizing risk to human health, impacts on the environment and cost. Uncertainty regarding the system's performance in dealing with particulates, and the limited potential for performance improvement through system optimization, featured in arriving at this conclusion.

Alternative 4 was also favoured when compared with both Alternatives 6 and 7, which are conceptually similar systems employing an electrostatically augmented scrubber and a wet electrostatic precipitator respectively. The main factor here was high cost associated, in particular, with effluent treatment and disposal since the capability of

both Alternative 6 and 7 was only slightly less than Alternative 4 in terms of their potential ability to minimize risk to human health and impact on the environment. The uncertain extent to which Alternative 7 has been applied on similar commercial installations was an additional factor in this assessment.

Alternative 8, involving semi-dry scrubbing of flue gas, was rejected because it could not achieve the minimum performance objectives for removal of acid gases, established for this assessment, i.e. it did not meet the basic acceptability criteria.

Hence, Alternative 4 was selected as the preferred rotary kiln incineration system for OWMC's Facility, subject to the satisfactory resolution of some detailed considerations during design optimization by OWMC's Incineration Technology Consultant. Such considerations were beyond the scope of this comparative evaluation of alternatives.

3.7.2 SENSITIVITY ANALYSES

Several options which might have an influence on the design of the rotary kiln incineration system are reviewed in the following paragraphs.

Off-Site Discharge of Scrubber Effluent

The evaluation is based on the treatment of liquid scrubber effluent by evaporation, with the concentrate being solidified for on-site disposal in the engineered landfill and the treated effluent being reused or discharged from the Facility. A sensitivity analysis was conducted to examine whether the offsite disposal of scrubber effluent, following less rigorous on-site treatment, would affect the conclusions presented in Section 3.7.1.

In this case it was assumed that the effluent would be treated to precipitate and remove heavy metal contaminants and solids (particulate) but that the resultant effluent, still high in dissolved solids, could be disposed of to a sewage treatment plant or discharged directly to Lake Erie or Lake Ontario.

The assessment of alternative incineration process systems will change only with regard to the high cost of scrubber effluent treatment and disposal attributed to some alternatives. The high capital cost of Alternative 4 would then no longer be justified and in our view, Alternative 1 would provide the best combination of performance and cost in achieving OWMC's principal goals.

However, the discharge of scrubber effluent in this manner would be contrary to OWMC's principal goals of minimizing risk to human health and impact on the environment. It would also be contrary to OWMC's philosophy of treating waste to the maximum extent possible.

This alternative approach therefore has not been considered any further.

Fabric Filter in Lieu of Electrostatic Precipitator

Fabric filters are being considered more frequently for applications involving the removal of particulate material from combustion flue gases. Consideration was therefore given to the use of a fabric filter in place of the electrostatic precipitator in Alternative 4.

Such an arrangement would have the following potential advantages:

- potential improvement in the efficiency of particulate removal in the sub-micron range, thereby further enhancing the excellent inherent capabilities of Alternative 4 in this regard and/or providing greater flexibility for system design optimization.

- potential improvement in heavy metal removal which would result from the above.

- potential for enhancing the removal of some residual organic species present in the flue gas (Ref: Moller[38]).

- potential for injection of reagents ahead of the fabric filter to effect a reduction in NO_x emissions, should this technology be proven in the future.

- reduced opportunity for lime carry-over into the wet scrubber, in the event that two-stage dry/wet scrubbing is adopted during design optimization. Lime carryover will cause troublesome gypsum formation in the wet scrubber.

- improved flexibility in removing particulate material in the flue gas having poor electrical characteristics (resistivity).

- improved performance in the removal of particulates during a power failure event.

- reduced capital cost.

However, a number of disadvantages or concerns also exist as follows:

- Experience with fabric filters on industrial waste incinerators has only been obtained over the last 2-3 years. This experience is from semi-dry scrubbing systems where the acid gases are already predominantly neutralized prior to them entering the fabric filter, and the gaseous environment in OWMC's rotary kiln incineration system could be more severe due to the potentially higher chlorine and sulphur content in the waste.

- Life expectancy of the filter bags are presently less than about three years, and replacement will result in an increased maintenance cost compared to the use of an electrostatic precipitator.

- Fabric filter materials are susceptible to destruction by overheating in the event of a process upset such as an irregularity in the spray dryer control system. Few fabrics are capable of

withstanding temperature in excess of 275°C (Ref: Power[38]). The temperature into the spray dryer is significantly in excess of this, (525°C).

- o "Blinding" of filter cloths is also a concern should moisture carryover from the spray dryer occur due to a process control malfunction. In this event filter bags must be replaced.

It was concluded that the selection of an electrostatic precipitator rather than a fabric filter for the preferred incineration process system (Alternative 4) is justified. However, the potential merits of a fabric filter are of sufficient interest to warrent further consideration during the optimization of system design by the Incineration Technology Consultants in Chapter 4.

Alternative Process Configurations

A number of alternative process configurations were examined using the shortlisted technologies listed in Section 3.6.2, pg. 49, to determine whether any of these offered any significant advantages over Alternative 4 irrespective of whether or not they have been satisfactorily demonstrated on an industrial hazardous waste incineration plant.

The first sensitivity analysis in this series examined the use of uncontrolled evaporative cooling in Alternative 3, in lieu of the controlled evaporative cooling tower design. It was concluded that such an arrangement would offer no apparent advantages, since the opportunity to dispose of scrubber effluent in the cooling tower and to remove dry particulate material ahead of the wet scrubber would be lost. This would result in a system design which embodied the worst characteristics of Alternatives 3 and 5, and few attributes such as energy recovery and dry removal of particulates ahead of the wet scrubber.

The second sensitivity analysis examined the addition of dry particulate removal in the form of an electrostatic precipitator ahead of the wet scrubbers for Alternatives 5, 6 and 7. This would reduce concern regarding the operation of the wet scrubber with high inlet particulate

concentrations. Alternative 5 would become similar to Alternative 1, one of the most highly ranked options along with Alternative 4, whereas Alternatives 6 and 7 would become significantly more costly process systems equivalent in many ways to Alternative 1 but with an electrostatically augmented scrubber or a wet electrostatic precipitator in lieu of or in addition to the final stage of the wet scrubber dealing with the removal of fine particulates and aerosols of metals. It is difficult to quantify what, if any, improvement in performance could be achieved from such an arrangement since there are no known installations in operation and Alternative 1 already has excellent capability in the removal of fine particulates.

Hence, while the addition of an electrostatic device as a further "polishing" stage to Alternative 1 is feasible, the relative merits are difficult to quantify and the significantly increased cost therefore impossible to justify. No further consideration was given to this option.

The third sensitivity analysis considered the use of a spray dryer and an electrostatic precipitator ahead of Alternative 5, 6 and 7 thereby converting them into "zero effluent" wet scrubber systems. Alternative 5 would become similar to Alternative 4, the preferred incineration process system, whereas Alternatives 6 and 7 would become significantly more costly as discussed above for the second sensitivity, and these extra costs would be impossible to justify based on available performance data. No further consideration was therefore given to this option.

The final sensitivity analysis examined the feasibility of enhancing the performance of Alternative 8, incorporating a semi-dry scrubbing system, by increasing the thermal capacity of the spray dryer reactor and thereby increasing the amount of reagent which could be introduced to the system. This would be achieved by further increasing the flue gas inlet temperature to the spray dryer in a similar manner to one process industry application reportedly installed in the USA (Ref: Orkild[37]). However, discussions with process suppliers identified that considerable uncertainties would be introduced by raising the inlet temperature above 525°C, already significantly higher than normally practiced in designs of

this type. The design would necessitate the use of a refractory lined spray dryer and spray nozzles for the introduction of reagent.

This option was therefore not considered any further.

3.7.3 SUMMARY

The rotary kiln incineration system which has been selected for OWMC's incineration plant consists of the following major components:

- o rotary kiln,
- o secondary combustion chamber,
- o waste heat recovery boiler,
- o spray dryer/reactor,
- o electrostatic precipitator, and
- o three stage wet scrubber.

Alternative designs have been identified for the heat recovery boiler and the possible use of a fabric filter in place of an electrostatic precipitator has also been retained for further consideration. Various options have also been identified to achieve a zero effluent scrubber system at high acid gas inlet concentrations.

All of the foregoing will be further examined in Chapter 4 which describes the design and optimization of OWMC's incineration plant.

CHAPTER 4
SYSTEM DESIGN AND OPTIMIZATION

4.1 INTRODUCTION

Previous sections of this report have described the methodology and rationale for selecting a preferred arrangement of technologies for inclusion in the conceptual design of the incineration plant. The evaluation focused on alternative technologies which are available for the cooling and treatment of combustion flue gases from the rotary kiln incinerator, prior to the cleaned gases being discharged to atmosphere via a stack.

The following sections describe the complete rotary kiln incineration system and measures taken to optimize the design and operation of this system to ensure that OWMC's goals of minimizing risk to human health, impact on the environment and cost, are achieved in a satisfactory manner.

The rationale for technology selection described in Chapters 2 and 3 of this report was prepared by Monenco Limited prior to the appointment of OWMC's Technology Consultants, who subsequently confirmed the selections.

System optimization described in Chapter 4 is primarily the result of work undertaken by OWMC's Incineration Technology Consultants, namely

- Environmental Elements Corporation, Baltimore, Maryland, U.S.A.
- Von Roll Limited, Zurich, Switzerland
- Hessische Industriemüll GmbH (HIM), Wiesbaden, West Germany

The design features incorporated in the incineration plant and described in the following sections, result from many years of experience acquired by these consultants in the design and operation of similar rotary kiln incineration facilities.

Chapter 4 commences with a description of the selected rotary kiln incineration system. It continues with a detailed consideration of how the various process components have been optimized to meet OWMC's goals. A section on plant operation includes a description of both design features and operational procedures which have been incorporated to mitigate potential effects upon the environment during normal operation and process upsets.

The Chapter concludes with the characterization of expected residual emissions from the incineration process.

4.2 DESCRIPTION OF SELECTED INCINERATION SYSTEM

Figure 9 provides a schematic illustration of the manner in which selected technologies have been arranged to form a rotary kiln incineration system. It also illustrates the interrelationships between the incineration plant, the physical/chemical treatment plant, the solidification plant and the engineered landfill.

Figure 10 is a pictorial flow diagram of the proposed incineration system with all the individual technologies identified. The location of the incineration plant on the Facility is shown on Figure 11, while Figures 12 and 13 show the arrangement of equipment in the incineration plant.

It will be observed from the layout of the incineration plant, that space has been allocated for a second unit at a later date, if required.

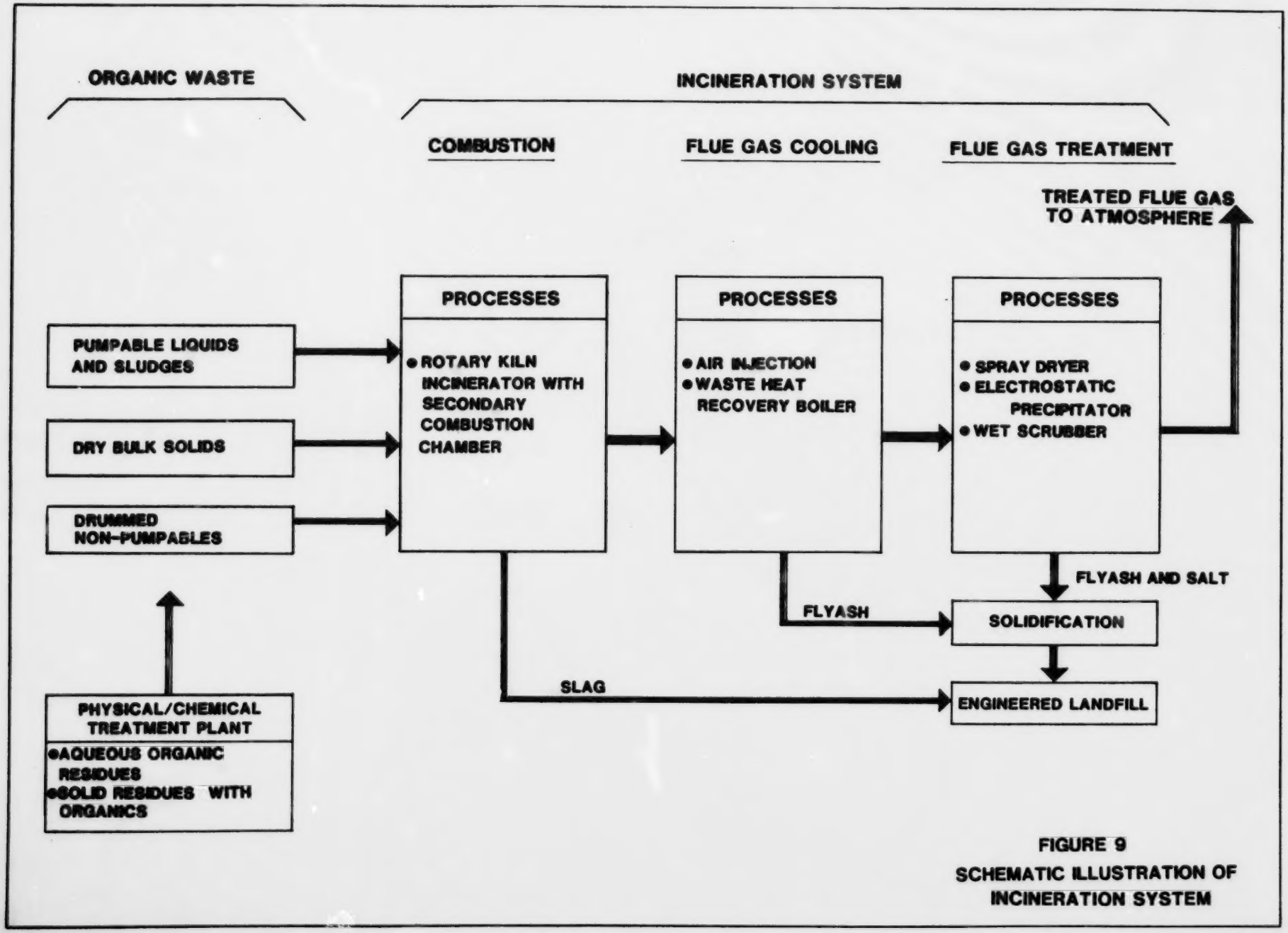


FIGURE 9
SCHEMATIC ILLUSTRATION OF INCINERATION SYSTEM

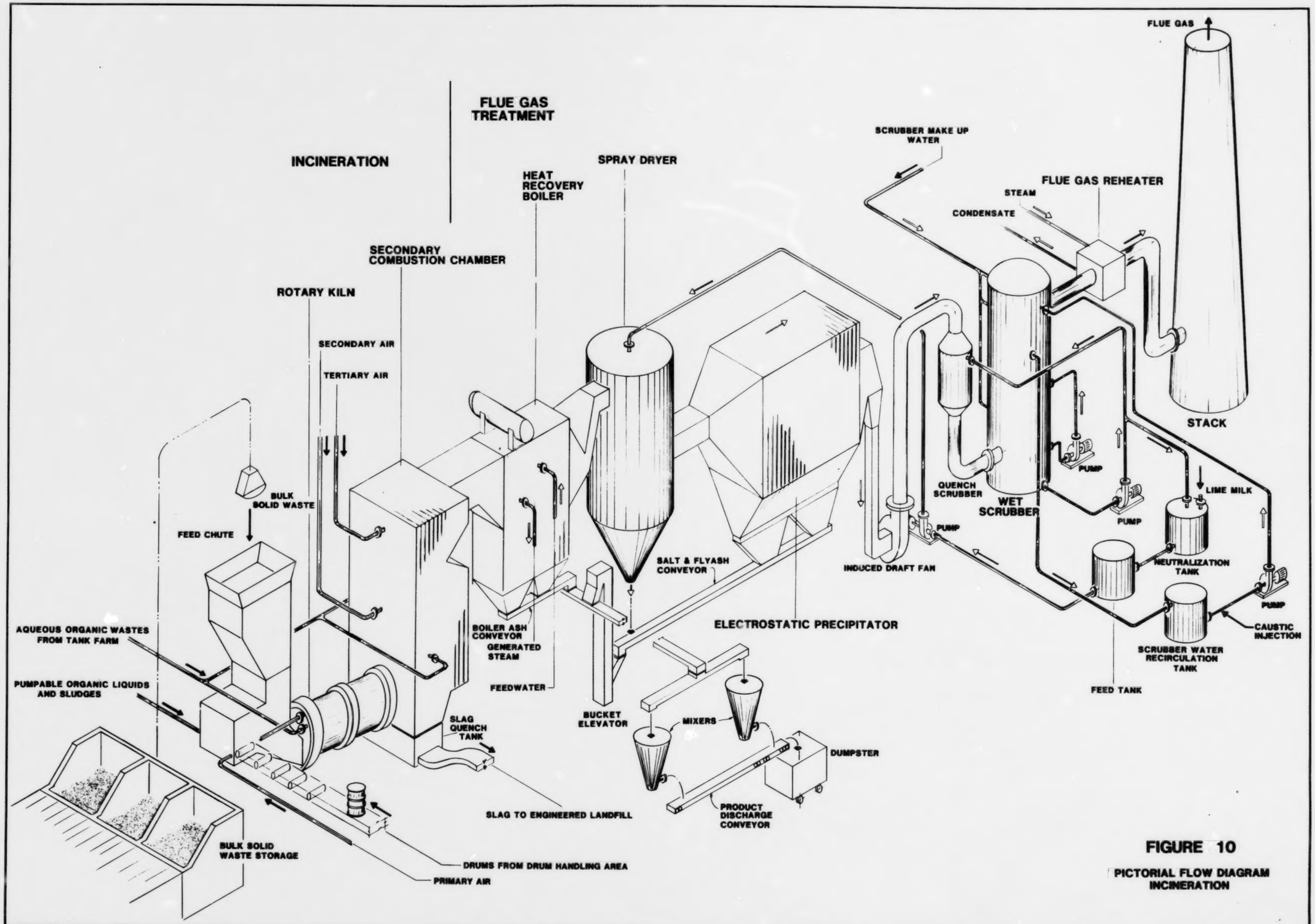


FIGURE 10

PICTORIAL FLOW DIAGRAM
INCINERATION

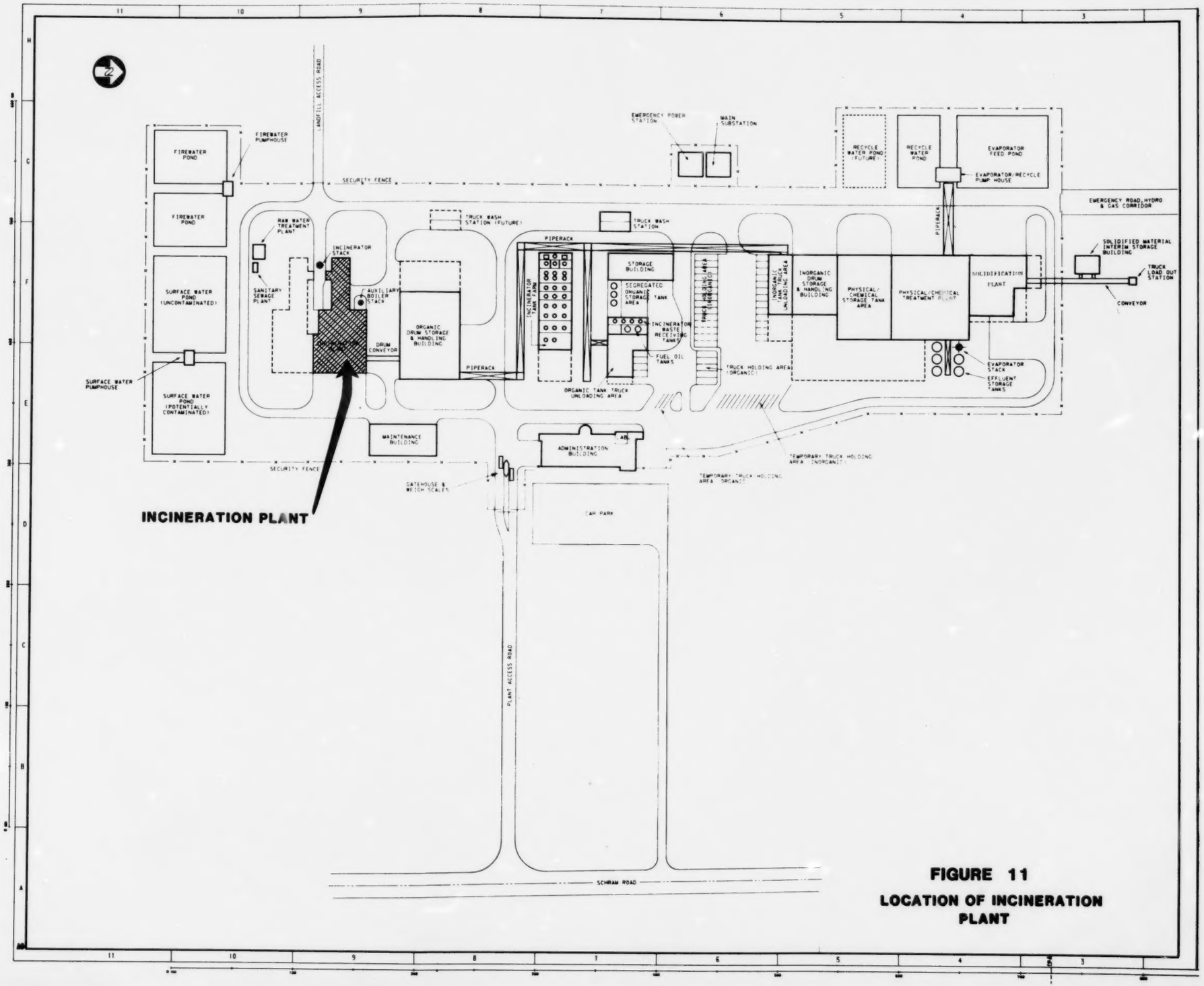


FIGURE 11

LOCATION OF INCINERATION PLANT

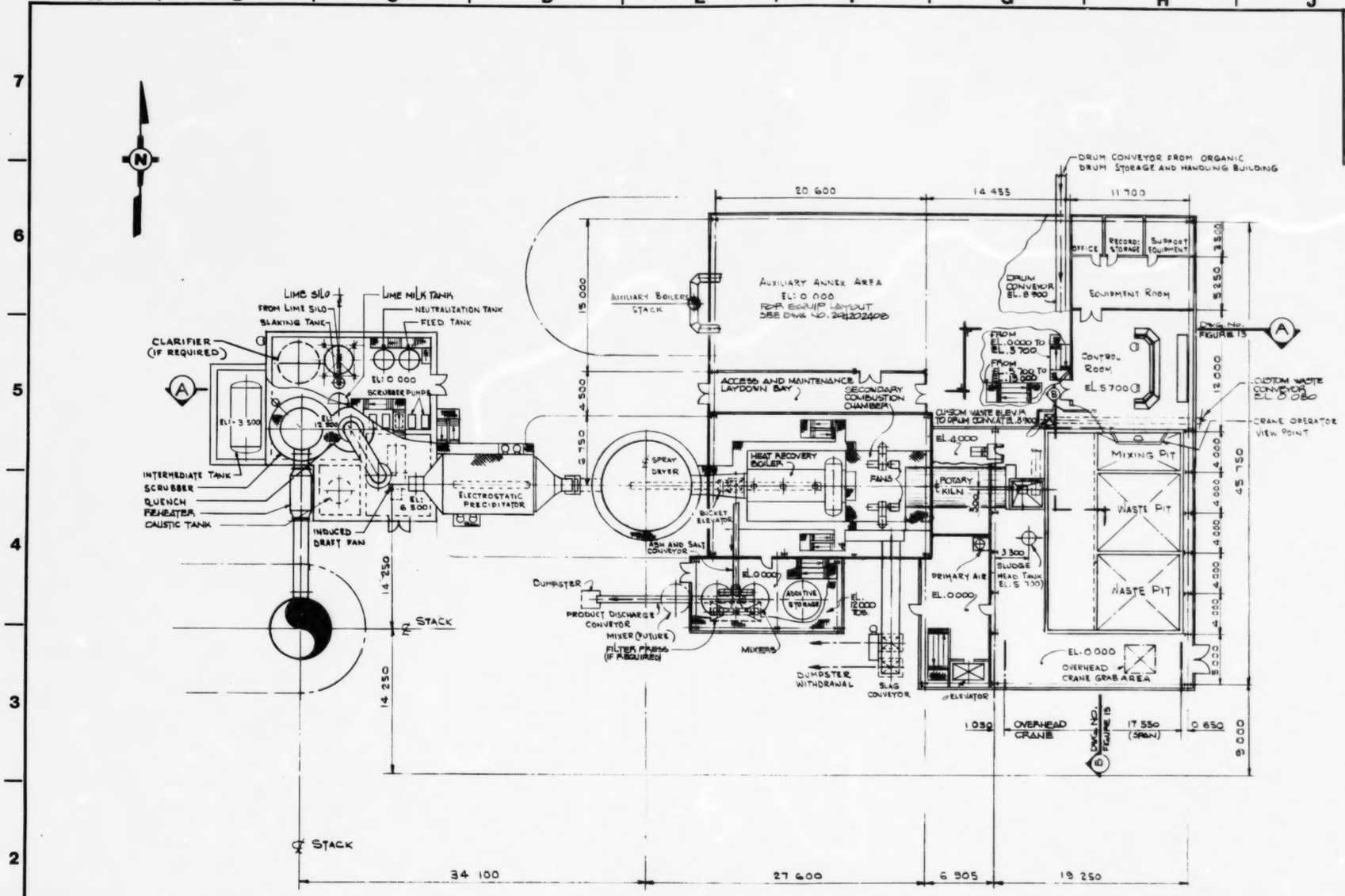
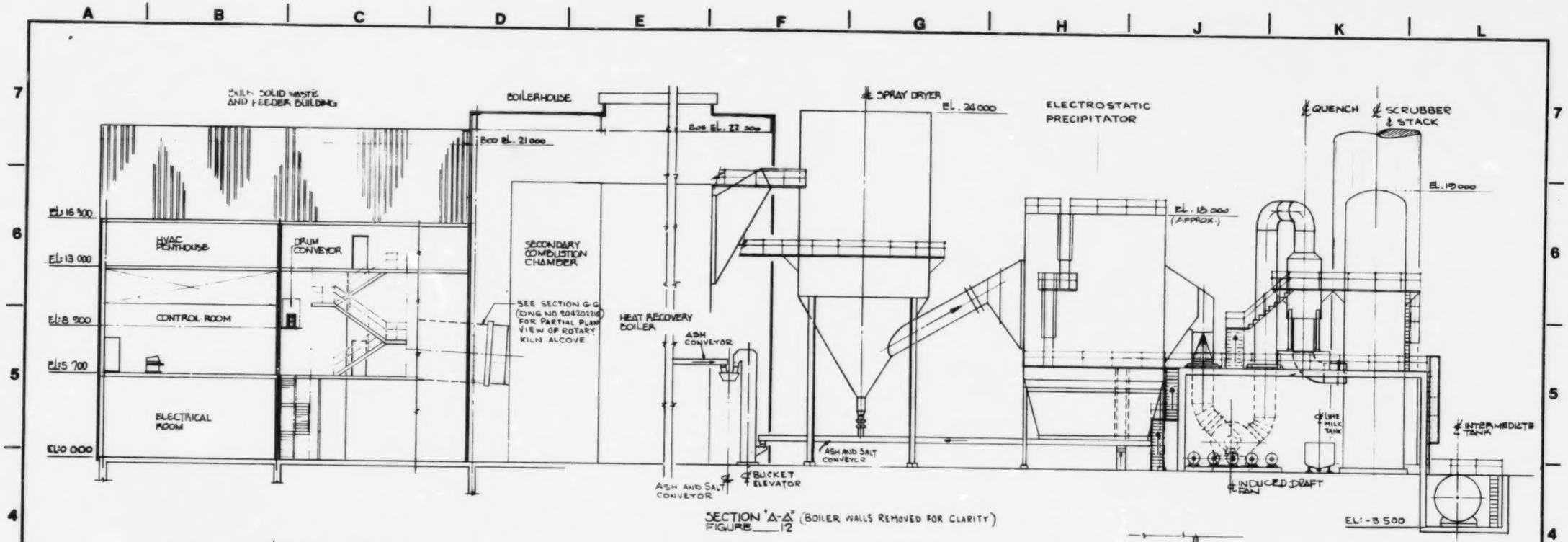
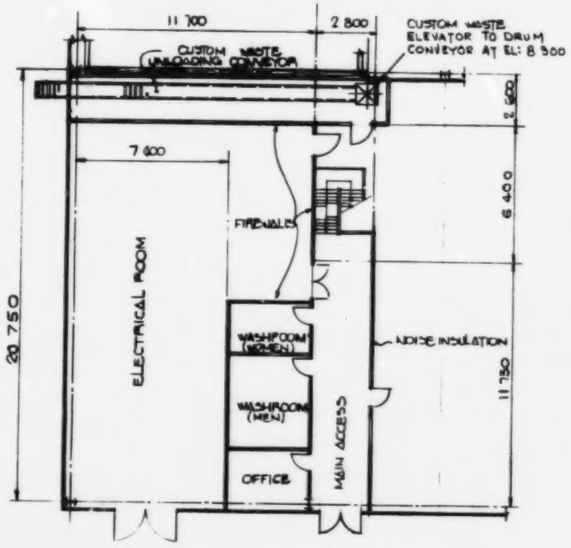


FIGURE 12

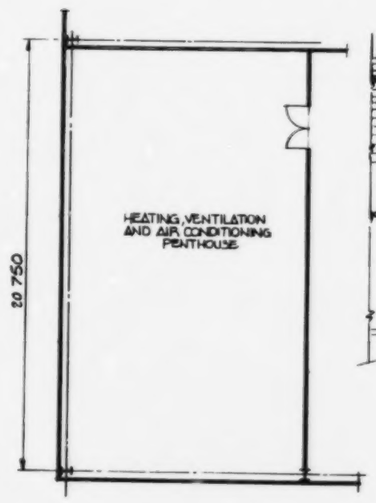
INCINERATION PLANT
CONCEPTUAL EQUIPMENT LAYOUT
PLAN



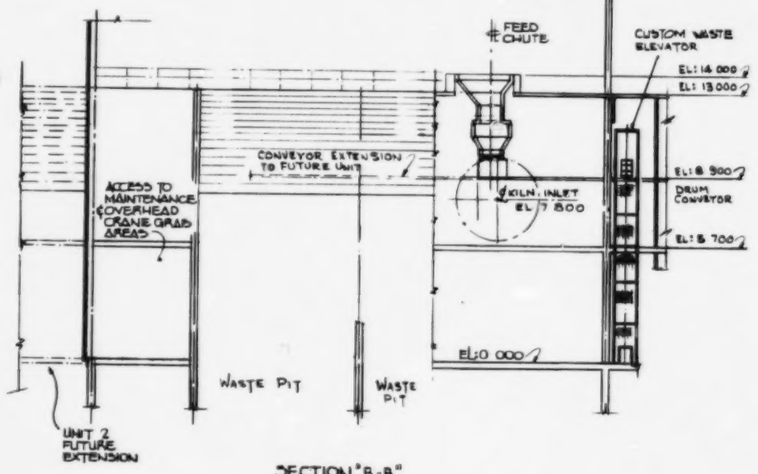
SECTION 'A-A' (BOILER WALLS REMOVED FOR CLARITY)
FIGURE 12



ELECTRICAL ROOM AREA
PARTIAL PLAN VIEW
EL. 0 000



HVAC PENTHOUSE
PARTIAL PLAN VIEW
EL. 13 000



SECTION 'B-B'
FIGURE 12

FIGURE 13
INCINERATION PLANT
CONCEPTUAL EQUIPMENT LAYOUT
SECTIONS

4.2.1 WASTE STORAGE AND HANDLING

Organic wastes will be fed to the incinerator in various physical forms including:

- o pumpable liquids and sludges,
- o dry bulk solids, and
- o drummed non-pumpable waste.

The unloading and storage of pumpable liquids and sludges at the Facility is described in the Process Area Report, General Facilities (Ref: Monenco Limited[9]). Also described are provisions for the preparation of batches of organic liquids and sludges prior to incineration.

Pumpable liquids and sludges will be fed to the rotary kiln from the blending tanks located at the incinerator tank farm. Aqueous organic wastes and aqueous organic residues from the physical/chemical treatment plant will also be pumped to the incineration plant via the incinerator tank farm.

Dry bulk solids will be delivered in trucks or containers directly to the incineration plant where they will be deposited and stored in enclosed in-ground waste pits. The waste will be transferred from the pits to the incinerator feed chute which provides for the delivery of waste directly into the rotary kiln via an air-lock. Solid residues from the physical/chemical treatment plant requiring incineration, will normally be fed to the incinerator in this manner.

Waste of varying physical and chemical forms may be delivered to the Facility in drums. The drum storage and processing facilities for organic wastes is described in the Process Area Report, General Facilities (Ref: Monenco Limited[9]). Pumpable waste in drums will normally be removed from the drums and transferred to the incinerator tank farm, whereas non-pumpable materials will remain in the drum and be transferred to the incineration plant by conveyor. The drums will be automatically fed to the incinerator feed chute via an air lock.

4.2.2 COMBUSTION SYSTEM

The combustion system comprises a rotary kiln incinerator complete with a secondary combustion chamber.

The rotary kiln consists of a 4 m diameter by 11 m long refractory lined cylinder, whose longitudinal axis is slightly inclined from the horizontal with the upper end housing the incinerator feed chute. The kiln rotates slowly, from 0.1 - 0.6 revolutions each minute, and supports a bed of burning waste introduced as pumpable sludge through lances located in the kiln front wall, or as bulk solids or drummed material introduced via the incinerator feed chute.

Liquid waste is introduced to the combustion system using lances which provide dispersion of the liquid thereby facilitating its combustion in suspension rather than on the floor of the kiln. Aqueous waste is also fed to the system through similar lances as those described for liquid wastes, but these may be located either in the kiln front wall or in the secondary combustion chamber.

Auxiliary fuel burners, designed for natural gas, are located in both the kiln front wall and also the secondary combustion chamber. These burners will be used for:

- o startup of the incineration process, by raising the incinerator temperature in a controlled manner,
- o maintaining the combustion temperatures above pre-determined limits during normal operation, if so required,
- o maintaining combustion temperatures above pre-determined limits during shutdown of the process, and for
- o controlling the rate of refractory cooling during a planned shutdown.

The feed end of the rotary kiln provides for the initial heating, volatilization and ignition of waste materials, with the centre portion of the kiln being the most active combustion zone. The discharge end of the rotary kiln achieves final burnout of solid materials. A pool of liquid

slag forms towards the discharge end of the rotary kiln, due to a combination of the operating temperature, normally above 1200°C, and the formation of a eutectic slag. Significant benefits result from operating the kiln in this so called "slagging" mode and these are discussed in Section 4.3.2 (pg. 132) dealing with optimization.

Combustion air is provided to the rotary kiln by a primary air fan which discharges air into ports provided in the front wall.

Combustion flue gases, including partially combusted volatile gases, flow from the rotary kiln to a refractory lined secondary combustion chamber where a combination of residence time, temperature, turbulence and the provision of additional (secondary) combustion air results in the completion of combustion and the destruction of organics with extremely high efficiencies.

The selection of operating temperatures, residence times and achievable destruction and removal efficiencies are further described later in this Chapter.

Liquid slag is discharged from the lower end of the rotary kiln as an inorganic residue. This is solidified by quenching in a tank of water which also contains a conveyor for removal of solid slag into containers. The water tank also provides a seal to prevent the ingress of air to the incinerator.

4.2.3 FLUE GAS COOLING SYSTEM

The evaluation of alternative heat recovery boiler types was presented in Chapter 3, from which it was concluded that insufficient differences existed to warrant a predetermination of boiler type by OWMC, and that the decision should be based on the recommendations of OWMC's Incineration Technology Consultants, using their considerable experience in both the design and operation of similar facilities.

A flue gas cooling system comprising a combination of air cooling and a convective type heat recovery boiler was unanimously recommended by

the Incineration Technology Consultants and accepted by OWMC. The rationale for this decision is presented in Section 4.3.3, (pg. 151).

Flue gas is cooled from a temperature of over 900°C following the introduction of secondary combustion air, to a temperature of about 750°C at the inlet to the waste heat recovery boiler, by the addition of tertiary air, thereby avoiding the deposition of fused flyash onto the boiler heat transfer surfaces.

Up to 16 t/h of superheated steam is generated in the waste heat recovery boiler in cooling the flue gases from 750°C to the temperature required at the inlet of the flue gas treatment system.

The tubes forming the heat transfer surfaces of the heat recovery boiler are mechanically "rapped" to remove any ash deposits which fall into hoppers located beneath the unit and are ultimately removed by a system of double flap valves and mechanical scraper conveyors.

4.2.4 FLUE GAS TREATMENT SYSTEM

The flue gas treatment system consists of a spray dryer, an electrostatic precipitator and a three stage wet scrubber arranged in a series configuration which provides for the removal of:

- o particulate material,
- o acid gases, and
- o heavy metals including aerosols which form during the gas cooling process.

A notable characteristic of this flue gas treatment system is that it has the performance attributes of a wet scrubber system but eliminates the need for treatment of scrubber effluent in the physical/chemical treatment plant, by disposing of this effluent by evaporation in the spray dryer. The dissolved solids from the scrubber effluent are released as dry particles in the spray dryer and removed from the flue gas in the electrostatic precipitator.

The flue gas treatment system is based on Alternative 4 described and evaluated as the preferred option in Chapter 3, but adjusted as a result of design optimization presented in Section 4.3.4, pg. 161. The optimized design differs from Alternative 4 in several respects, the most important ones being as follows:

- o The use of a convective heat recovery boiler enables the required thermal (evaporative) capacity of the spray dryer to be achieved with a lower flue gas inlet temperature.

- o Operation of the wet scrubber liquor at significantly higher total dissolved solids concentrations than were conservatively adopted for evaluation purposes, reduces the quantity of scrubber effluent requiring disposal.

Hence, the Incineration Technology Consultants chose the above route to achieve a "zero effluent" scrubbing system, rather than adopting the two stage scrubbing system described for Alternative 4, pg. 67.

Flue gases enter the spray dryer at a temperature of 325^{o}C and are cooled, by the evaporation of scrubber effluent, to 160^{o}C prior to them entering the electrostatic precipitator. Dissolved salts are released from the scrubber effluent as dry solid and removed from the system by the electrostatic precipitator, along with flyash. Some solids will also be removed from the bottom of the spray dryer.

An induced draft fan is located after the electrostatic precipitator and provides for the movement of combustion flue gases through the process system. The control vanes on the induced draft fan operate automatically to maintain a slight negative pressure in the rotary kiln incinerator to avoid the release of gases to atmosphere through incinerator seals. The incinerator, waste heat recovery boiler, spray dryer and electrostatic precipitator all operate under negative pressure, whereas equipment down stream of the induced draft fan, including the wet scrubber and stack all operate under positive pressure.

The wet scrubber has three stages as described below:

- The first stage is a quench section which cools the flue gases to saturation temperature (62°C) by recirculating scrubber liquor to a fixed throat venturi. Some acid gases are also removed from the flue gases in this section.

- The second stage of the wet scrubber comprises a packed bed section for the removal of hydrogen chloride (HCl) and hydrogen fluoride (HF). Flue gas will enter the bottom of the tower and flow upward through a packed bed section counter to the flow of scrubbing liquor. The recirculated liquor will be uniformly distributed over the packing through low pressure non-clogging spray nozzles. The large surface area of the packing material will maximize adsorption of acid gases and demisters located over the spray manifolds will prevent liquid entrainment.

  The HCl and HF concentrations in the scrubber liquor will be maintained by bleeding off liquor to the quench sump. The bleed-off from the quench sump will be neutralized by the addition of a 25% solution of hydrated lime ($Ca(OH)_2$) before being pumped to the spray dryer.

- Sulphur dioxide will be removed in the final stage of the scrubber, by using a solution of caustic soda (sodium hydroxide) recirculated to a system of multiple small venturis through which the flue gases pass and are thereby intimately brought into contact with the scrubbing liquor. This system of venturis, referred to as Ring Jets™ (see footnote 1) will also remove fine particulates such as heavy metal aerosols from the flue gas as agglomeration and impaction forces will be used to collect and entrain the fine particulates in the recirculated scrubber liquor.

  A bleed-off from the recirculated scrubber system to the packed bed stage of the scrubber will maintain the concentrations of sodium

1. Ring Jet™ is a trademark of Ciba-Geigy, Ltd., Basel, Switzerland.

sulfite and sodium sulfate at required levels. The pH of scrubber liquor will be controlled automatically at a value of about 6.5 with the addition of a 50% solution of caustic soda. Makeup water will be added to the scrubber circuits, as required.

A demister system will be located at the outlet of the scrubber to prevent carry-over of entrained liquids.

4.2.5 FLUE GAS REHEATING

Flue gases leaving the flue gas treatment system will be reheated using an indirect steam/gas heat exchanger to raise the temperature from 62°C to about 130°C, prior to their being discharged to atmosphere via a stack. The rationale for including flue gas reheating in the process design is included in Section 4.3.5, pg. 186 dealing with system optimization.

4.2.6 STACK

A 60 m high stack will be provided to discharge treated flue gases to atmosphere. The stack structure will be designed to accommodate the addition of a second flue, should a second incineration system be installed at some future date. A flue diameter of approximately 1.3 m will maintain a flue gas exit velocity of approxmately 20 m/s when the incineration system is operating at full capacity.

The stack will also house water storage tanks for the supply of water to the wet scrubber during a power failure.

The rationale for selection of stack height is included in Section 4.3.6, pg. 188 dealing with optimization.

4.2.7 RESIDUE HANDLING SYSTEMS

Solidified slag from the rotary kiln incinerator will be transported to the engineered landfill in containers, for ultimate disposal along with solidified residues from the Facility.

Solid residue from the waste heat recovery boiler, spray dryer and electrostatic precipitator will be mechanically conveyed, on a continuous

basis, to mixers located at the incineration plant, where the materials will be mixed with solidification reagents prior to being transported to the landfill in containers.

4.2.8 REAGENTS STORAGE AND HANDLING

The main reagents that are required for the incineration plant are caustic soda (NaOH) and hydrated lime ($Ca(OH)_2$) for the flue gas scrubbing system, and morpholine, sodium sulphite and tri-sodium phosphate for use in the boiler feedwater treatment system.

Flue gas treatment reagents will be delivered by truck and stored in bulk tanks adjacent to the wet scrubber building.

Other reagents and chemicals will be delivered in drums or in bags, in accordance with industry practice, and transferred to chemical dosing tanks located in the auxiliary plant area.

4.2.9 AUXILIARY SYSTEMS

The auxiliary annex area of the incineration plant will incorporate the following major items of auxiliary thermal equipment:

- o auxiliary boilers,
- o boiler feedwater treatment system,
- o boiler feedwater system, including deaerator, and
- o condensate system.

The design of auxiliary thermal systems, including the rationale for numbers and sizes of boilers, are addressed in Section 4.3.9, (pg. 190).

4.2.10 INSTRUMENTATION & CONTROLS

The incineration plant will be operated continuously, 24 hours a day, 7 days a week and will be controlled from a central control room located at the incineration plant.

Figures 12 and 13 (pgs. 108 & 109) show the control room located on the second floor of the incineration plant building, at one end of the

waste pits. This location permits observation of the waste storage pits and control of the bulk solid handling crane grab, from the control room.

Control, process data acquisition and alarm annunciation will be handled by the process control system which includes modern distributed digital controls with keyboard/CRT operator interfaces. Many of the process control functions will be automatic including safety features described in Section 4.4 dealing with operational considerations.

Functions which will routinely be controlled automatically in normal operation include the following:

- Organic liquid feed rate control based on the oxygen concentration level in the flue gas at the precipitator outlet.

- Induced draft fan damper positioning control based on the static pressure in the secondary combustion chamber.

- Front wall coolant heat exchanger damper control based on the temperature of the coolant leaving the front wall coolant jacket.

- Spray dryer feed (scrubber effluent) rate control based on the flue gas temperature at the spray dryer outlet.

- Scrubber liquor pH value in the circulating scrubbing water fed to scrubber Ring Jet™ nozzles.

- Tertiary air damper positioning control based on the flue gas temperature at the boiler inlet.

- Three element boiler feed water control based on steam flow, boiler drum level and feed water flow.

Plant interlocks and safety shutdown sequences will be provided to ensure that risk due to equipment maloperation, equipment malfunction or process upset is minimized.

An uninterruptible power supply system will be provided to safeguard control systems.

The flow of flue gas and the concentration of oxygen in the flue gas leaving the precipitator, the temperature of the flue gas in the secondary combustion chamber just prior to secondary air injection, the concentration of carbon dioxide in the stack flue gas, and the rate at which each waste is fed to the incinerator will be monitored and recorded continuously. The concentration of the following stack gas contaminants will be monitored, to ensure optimum operation of the incineration system:

- o Carbon Monoxide (CO)
- o Sulphur Dioxide (SO_2)
- o Nitrogen Oxides (NO_x)
- o Hydrogen Chloride (HCl)
- o Total Hydrocarbons (THC)

(Note: Organic carbon content will be determined by the Flame Ionization Detection method. Under US Environmental Protection Agency regulations, this organic carbon content is expressed as a methane equivalent to indicate total hydrocarbon content of the flue gas.)

A closed circuit television monitoring system will permit control room operators to observe strategic parts of the operation, including views into the rotary kiln, and parts of the waste feed system.

4.3 SYSTEM OPTIMIZATION

This section examines how the design of the incineration plant has been optimized to achieve OWMC's goals of minimizing risk to human health, impact on the environment and cost. Specific features which are designed to mitigate potential impacts on the environment are also highlighted in this section.

Each part of the incinerator described in Section 4.2 is further examined in the following paragraphs.

4.3.1 WASTE STORAGE AND HANDLING

The types and quantities of candidate wastes for incineration have been previously identified in Table 1, pg. 8.

A further assessment of this information has resulted in the following estimate of typical waste feed to the incinerator, based on the unit operating 7000 hours/year at a 90% capacity factor, as previously established for design purposes.

Waste Type	Typical Quantity
Solid Waste	2 320 kg/h
Sludges	1 255 kg/h
Aqueous Liquids	95 kg/h
Organic Liquids	1 090 kg/h
Total	4 760 kg/h

The manner in which these wastes will be sent to the incinerator was estimated to be 1250 kg/h as solid waste fed by the crane grab, 1620 kg/h fed in drums and 1890 kg/h pumped to the incinerator via lances. This assumes that 550 kg/h of the sludge and 1070 kg/h of the solids indicated above will be sent to the incinerator in drums.

The inherent uncertainty of the waste data however requires that provisions be included in Facility design for significant variations in both of the type, physical form and relative quantities of waste requiring incineration. Waste storage and handling systems will be designed with due consideration for such variability.

Pumpable Liquids and Sludges

The incinerator tank farm described in the Process Area Report, General Facilities (Ref: Monenco Limited[9]) provides for separate storage of the following organic wastes:

- o Organic liquids, including solvents and oils,
- o Aqueous organic liquids,
- o Organic sludges,
- o Halogenated wastes, and
- o Segregated organic waste.

A total storage capacity equivalent to about six weeks of pumpable liquids and sludges at the initial plant capacity provides significant flexibility in dealing with short term changes in the types of wastes delivered to the Facility. It also enables the Facility to continue accepting these wastes when the incinerator is shutdown for maintenance periods which could exceed 2 - 3 weeks when refractory linings are to be replaced.

Four blending tanks are provided at the tank farm, two 60 m^3 tanks for sludges and two 60 m^3 tanks for liquids, which provide flexibility in the preparation of waste batches prior to incineration.

One blending tank each for sludges and liquids will be in service, while the others are being prepared for service. The capacity of these tanks enables samples of the blended wastes to be taken for verification of principal characteristics such as chlorine content or heating value, should this be required prior to incineration of the batch.

The preparation of waste blends also enables the incinerator to operate for extended periods on a reasonable consistent feedstock, thereby providing for more stable and consistent performance and easier control.

These features will provide additional assurance that the waste being fed to the incineration system will not exceed design limits and that emissions to the environment will be maintained at consistently low levels.

Aqueous organic waste will normally be pumped directly from the storage tanks to the incinerator and will not normally be blended.

Segregated organic wastes such as PCBs will preferably be transferred directly to the incinerator from delivery tanks under nitrogen pressure applied to the tank. This will avoid contamination of pumps, potential leakage from pump glands and minimize opportunities for inadvertant releases to the environment or risk to operations and maintenance personnel. However, provision is also made for the storage of such wastes in the tank farm area and for transfer by pump to the incineration plant, if necessary.

The following provisions for the introduction of pumpable liquids and sludges to the incinerator demonstrate the inherent flexibility of the system in dealing with variations in types and quantities of wastes from the typical quantities previously estimated.

Waste Type	Number of Lances	Location	Design Capacity kg/hour
Organic Liquids	1	Kiln	2 000
Organic Sludges	1	Kiln	4 000
Aqueous Organics	1	Kiln	500
Aqueous Organics	2	Secondary Chamber	2 x 500
Segregated Organic Wastes	1	Kiln	300

The installed capacity for disposal of aqueous organics can be seen to provide great flexibility in the disposal of aqueous organic residues from the physical/chemical treatment plant, should this be required.

Dry Bulk Solids

A basic philosophy adopted in the design of OWMC's incineration plant, was to avoid the storage of waste containing free liquids or solid wastes containing high vapour pressure organics in open pits. Such wastes will be either pumpable and stored in the incinerator tank farm, or non-pumpable and be delivered, stored and fed to the incinerator in drums.

This philosophy was adopted to minimize the opportunity for release of potentially harmful organic vapours to the environment.

The waste storage pits located at the incinerator plant therefore will be used to store dry solid materials of an essentially non-volatile nature.

Three pits are provided, two each of 300 m^3 capacity for the storage of waste and one of 150 m^3 capacity for the premixing of waste prior to it being fed to the incinerator. The storage capacity provided by these pits is equivalent to about 2 weeks at the typical feed rate previously indicated, thereby providing considerable flexibility in the levelling of short term fluctuations which will inevitably occur in operation.

Crushed drums and drum caps will be transferred to the pit from the drum handling facility.

The waste pits will be designed with a double containment system to prevent the ingress of water to the pits during high water table conditions, and to minimize the possibility of contaminant leakage to the environment arising from free liquids inadvertently deposited with, or which separates from, the solid dry waste. An inspection sump will be provided to permit the detection of free liquids at the bottom of the pits which will be approximately 5 m below ground level.

Solid waste will be fed from the pits to the incinerator feed chute hopper by means of the overhead crane which will also be used to mix the solid waste in each separate pit section. The crane will be equipped with a 1.25 m^3 bucket designed to transfer a variety of shapes and waste consistencies. This provides ample flexibility for the feeding of solid waste to the incinerator.

The operator will be able to observe crane movements through a window in the Control Centre and this location will provide line-of-sight contact with all areas of the pit area except for the feed hopper at the top of the rotary kiln. This area will be viewed using a closed circuit television camera and monitor. The ascent of the load and control governing acceleration, deceleration and routing to the hopper will be automated and an interlock will allow travel to the hopper only when the kiln is ready to receive a load of solid waste. The crane will be equipped with a weighing device to limit the weight of a load, prevent overcharging the kiln and to record processing data.

Solid waste fed to the kiln by the overhead crane will be received in a feed chute hopper configured with steeply sloping sides. The hopper will be equipped with a hydraulically operated double gate system to limit air leakage into the kiln or escape of combustion gases from the kiln during bulk solid waste feeding as illustrated on Figure 14. The first gate or feed gate will be opened to receive the waste from the crane. After the first gate is closed, a second or discharge gate will be opened allowing the waste to fall through the feed chute and into the kiln.

The size of bulk solid waste pieces and containers fed to the kiln will be limited by the dimensions of the feed system. The system will be designed to receive 320 liter overpack drums and solid waste pieces up to 1.0 m long by 0.5 m wide and deep.

While precautions will be taken to control the type of waste deposited in the pits, proper ventilation is considered necessary to minimize

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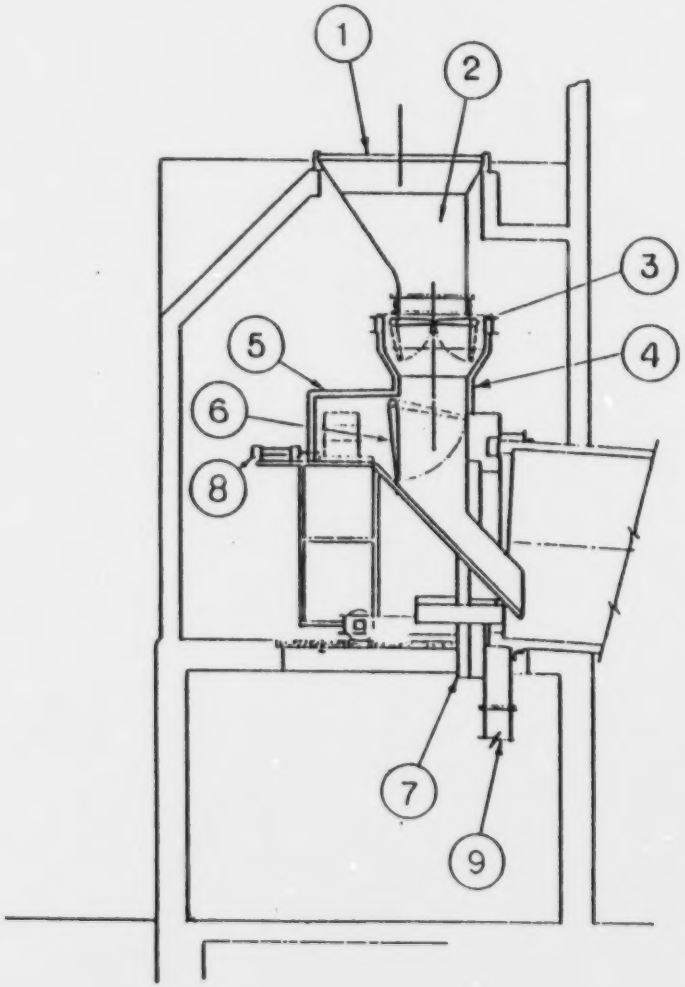

LEGEND

1. HOPPER FEED GATE
2. SOLID WASTE FEED HOPPER
3. HOPPER DISCHARGE GATE
4. FEED CHUTE
5. DRUM PRECHAMBER
6. PRECHAMBER DISCHARGE GATE
7. ROTARY KILN FRONT WALL
8. DRUM PUSHER
9. DEBRIS CHUTE

FIGURE 14

VonRoll ENVIRONMENTAL ELEMENTS CORPORATION

OWMC TREATMENT FACILITY

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TYPICAL FEED SYSTEM

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releases of dust and organics to the environment during vehicle unloading and also to eliminate the opportunity for concentrations of organics to build up in the pit enclosure.

For this reason the feed pit enclosure will be ventilated by drawing primary combustion air for the incinerator from this building. Additional roof mounted ventilation fans will be installed for use when the incinerator is not working or to supplement the primary air fan, should the need arise.

Special provisions are proposed for the feeding of custom waste (eg. hospital waste or security documents) to the incinerator since it is believed that for health or security reasons, these materials should not be processed in the drum handling facility and neither should they be deposited in the waste pits for feeding with the crane grab. Either of these approaches might result in extended delays prior to the wastes being destroyed, inadvertent opening of packaging and associated health concerns. Therefore, a separate feed system is provided at the incineration plant to convey custom waste in closed containers directly to the incinerator feed chute where they will be handled by the drum feeding system, on a priority basis, and thereby deposited in the rotary kiln shortly following delivery to the Facility. This system minimizes risks to human health and the environment in the processing of certain custom wastes.

Drummed Waste

The drum handling systems for organic waste are described in the Process Area Report, General Facilities (Ref: Monenco Limited[9]).

Drums containing mainly wet or highly volatile non-pumpable wastes, which are unsuitable for depositing in the waste pits, will be transferred to the incineration plant on an elevated conveyor from the organic drum handling building. The design of the drum handling system (Ref: Monenco Limited[9]) provides for intermixing of drums containing different types of wastes and thereby avoiding operational difficulties which might otherwise result should drummed waste of one type, such as that having high or low heat content or having a specific contaminant type, be repeatedly fed to

the incineration system. On the other hand, if feeding drums containing a certain type of waste is desired this can also be achieved. Feeding of such batches may be advantageous under certain conditions if it allows the incinerator and flue gas cleaning system to be trimmed to the specific needs of a certain waste type.

The drummed waste will be conveyed to the incinerator feed chute where a prechamber, which serves as an air lock to limit air leakage into the kiln or the escape of combustion gases to atmosphere, provides for the delivery of drums into the kiln. The prechamber will be equipped with a hydraulically operated double gate system. With the second or discharge gate at the feed chute closed, the first or feed gate at the conveyor will be opened and one drum will be pushed into the chamber by a hydraulically operated pusher plate. Once the pusher plate is retracted, the feed gate will be closed. Then, the discharge gate will be opened and a second pusher plate will push the drum into the feed chute at the front wall of the rotary kiln. This is also illustrated on Figure 14.

Up to 10 drums an hour can be fed to the incinerator in this manner providing a maximum capacity, based on full drums weighing 200 kg each, of 2000 kg/h. This provides ample flexibility in dealing with quantities of organic drummed waste expected at the Facility.

The arrangement for the feeding of drummed waste to the incineration system minimizes risk to operations personnel and also minimizes the release of fugitive emissions to the environment. The system also provides flexibility in the pre-selection of different waste types to be fed to the incineration system in drums.

4.3.2 COMBUSTION SYSTEM

The combustion system, comprising the rotary kiln and secondary combustion chamber, is the heart of the incineration process system since it is here that organic materials are destroyed by high temperature thermal oxidation. The following paragraphs address important aspects of the system design

developed and optimized by the Incineration Technology Consultants, and incorporating experience from many successfully operating installations around the world.

Waste Feeding

Waste feed lances will be used to inject pumpable waste in a stream so that heating, vaporization and ignition of the waste occurs in the first section of the rotary kiln. Waste liquids will be injected in a dispersed stream to achieve optimum combustion conditions. Lances are preferred to "small nozzle" atomizers, since the latter are prone to plugging due to solids in the waste.

The following lances are provided:

- One water cooled sludge lance located in the front wall of the rotary kiln and equipped with a special end-piece that utilizes steam to break up the stream of sludge as it leaves the lance. This arrangement distributes the sludge evenly over the top of the other waste in the kiln, thus assuring complete combustion of the sludge. The steam also serves to cool the sludge lance.

- One water cooled organic (liquid) waste lance located in the front wall of the rotary kiln.

- One aqueous waste lance located in the front wall of the rotary kiln. This lance is cooled by the flow of waste.

- Two aqueous waste lances, located in opposing walls of the secondary combustion chamber.

All lances have provisions for steam atomization which disperses the waste material into droplets, thereby increasing the surface area of the waste exposed to the combustion environment. The droplets formed by the lances are not as fine, however, as those produced by small nozzle atomizers in conventional burners.

The solid waste feed system for bulk solids and drummed material will be equipped with a series of interlocks to ensure that the following conditions are met at all times.

- Bulk solid waste from the crane and drums from the feed conveyor are fed in a sequential manner and at a sufficient spacing to prevent thermal overloading of the rotary kiln.

- The bulk solid waste feed gate is opened and the crane load emptied only when the hopper discharge gate is closed and the drum prechamber is empty.

- The bulk solid waste hopper discharge gate is opened when the hopper feed gate is closed.

- The drum prechamber feed gate will be opened and the feed gate pusher activated only when the prechamber discharge gate is closed and the solid waste hopper is empty.

- The drum prechamber discharge gate will only be opened and the discharge pusher activated only when the prechamber feed gate is closed.

The exit of the feed chute will extend into the kiln so that drums and loose solid waste are injected well into the first zone of the kiln. This design feature will eliminate both erosion of the refractory brick on the front wall of the kiln and damage to the burners and lances in the front wall from tumbling waste. The front end of the kiln will be tapered to prevent the waste from flowing backwards. The feed chute and prechamber will be liquid cooled to minimize thermal stress and prevent ignition of waste due to excessively high temperatures.

Three natural gas fired burners will be installed, one in the front wall of the rotary kiln and two in the secondary combustion chamber. Each burner will be sized for 450 kg/h of natural gas.

The burner in the front wall of the rotary kiln will be of a dual fuel design to allow for either the combustion of natural gas alone or the simultaneous combustion of both natural gas and segregated organic wastes such as PCB contaminated waste liquids.

Rotary Kiln

Staged combustion of the waste provides for a stable and controlled combustion process. The first stage of combustion takes place in the evaporation zone of the kiln where the waste is heated gradually and the organic content vaporized. Very little ignition of the waste takes place during this first stage. Combustion air is introduced at a predetermined rate near the bottom of the kiln front wall, below the waste feed systems, and an excess air ranging from 55% - 75% is normally achieved within the kiln. The method used for feeding aqueous waste and combustion air into the kiln enhances the controlled heating and vaporizing process. A steam to air heat exchanger is proposed, to preheat combustion air during winter and also when incinerating low heat content wastes.

Primary combustion of the waste takes place in the second zone of the kiln where oxidation of the now vaporized organic waste occurs as it mixes with the combustion air.

Combustion of solid material is completed in the final zone of the kiln whereas volatilized organics pass into the secondary chamber where their combustion is completed. Figure 15 shows the configuration of the rotary kiln and the stages of combustion.

This method of staged combustion and, in particular, the independent introduction of waste and combustion air into the kiln, contributes to a reduction in the formation of nitrogen oxides as compared to emissions from other combustion processes.

The feeding of almost all of the waste through the front wall of the rotary kiln and the consequent operation of the lower end of the kiln as well as the secondary combustion between 1000 and 1400°, depending on waste type, was adopted for the following reasons:

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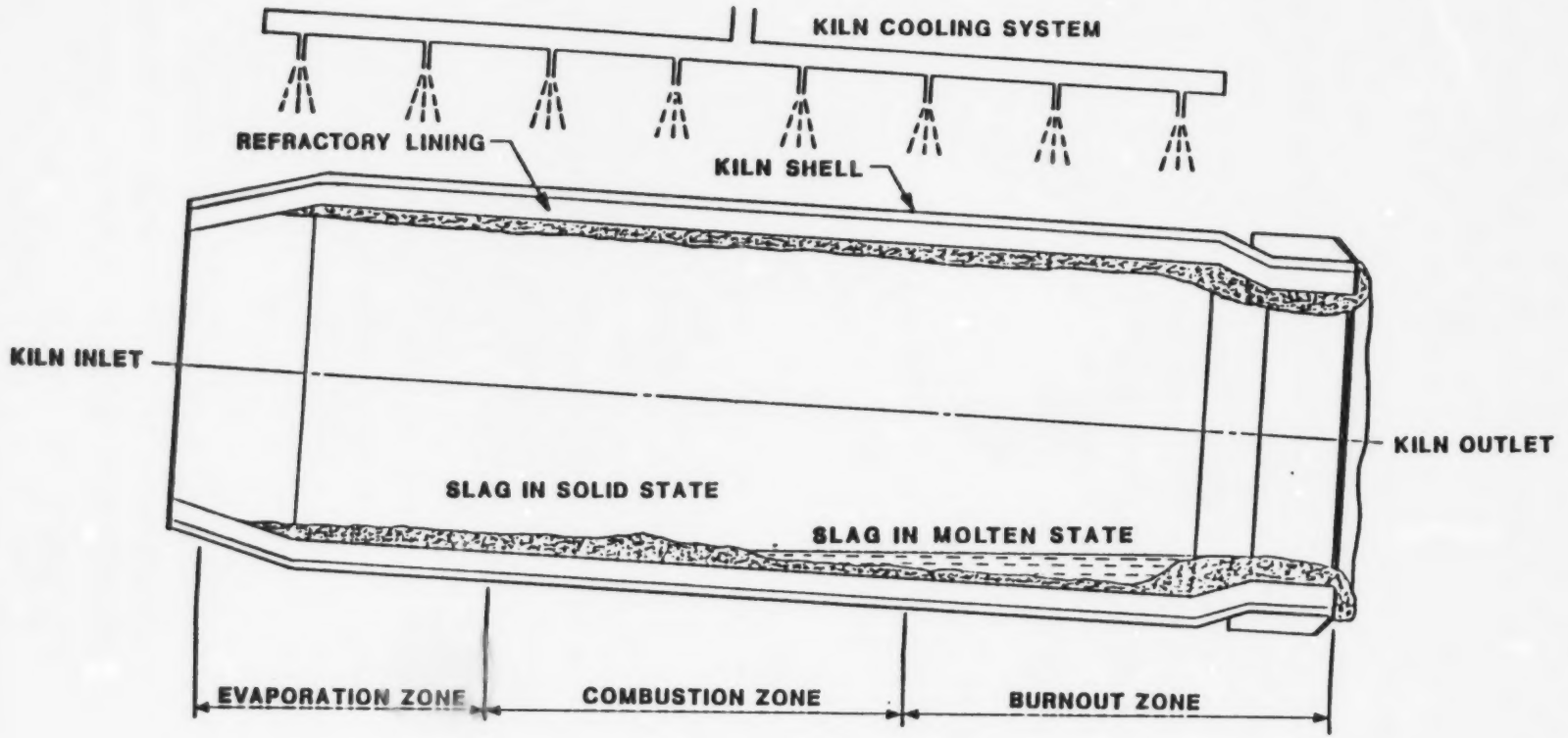

FIGURE 15

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OWMC TREATMENT FACILITY

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TYPICAL ROTARY KILN

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- It is the most thermally efficient method and enables waste of very low heat content to be burnt without the addition of auxiliary fuel. Were the kiln operated at lower temperatures, large quantities of primary air would be required and additional fuel or waste would have to be burned in the secondary combustion chamber to raise the temperature as required for the destruction of organics.

- It also assures a high degree of combustion efficiency and allows for the addition of secondary combustion air to minimize carbon monoxide emissions.

- It increases the residence time of organics in the high temperature zone of the combustion system, since a portion of the rotary kiln is operating between 1000 and 1400°C as well as the secondary combustion chamber.

A demonstration of the effectiveness of the above features is that incineration systems of the Von Roll design have been able to achieve not only high destruction and removal efficiencies, but also very low emissions of carbon monoxide and hydrocarbons.

As a result of the mode of kiln operation described on page 130 and above, salts and other inert material contained in the waste feed will melt in the kiln. A molten slag pool forms by the combination of non-combustible residue from the waste and silicon based compounds which are injected into the kiln periodically to adjust the consistency of the slag. The eutectic combination of non-combustible waste and silicon has a melting temperature lower than the flue gas temperature in the second half of the kiln. This operating condition results in the following beneficial performance characteristics:

- In the Von Roll design, a profiled kiln end is provided to trap or "pool" the melted inert material before discharge. The result is an exceptionally high degree of burn-out of the organic residue, with less than one percent weight loss on ignition of the slag. The loss on ignition for residue from rotary kilns operating in the dry or "non-slagging" mode is often in the order of 5%.

- In addition to achieving a high degree of burn-out of organics, the liquid slag provides for some fixation of heavy metals in the residue which reduces the leaching of heavy metals in the landfill. The molten slag pool also melts steel drums and other steel containers containing waste.

- The melting of salts and similar inert material also provides a coating on the inside of the rotary kiln, thereby protecting refractory in the kiln from high temperature corrosion attack in high chlorine and sulfur environments. In the Von Roll design, a water spray on the surface of the kiln assists in cooling the refractory and forming a layer of slag on the refractory surface. This technique has been demonstrated to be effective in significantly extending refractory life.

All of the features described play an important role in ensuring that OWMC's incineration plant will achieve their principal goals in minimizing risk to human health, impact on the environment and cost.

Secondary Combustion Chamber

Complete combustion of organics in the flue gas and fly ash particles is achieved with a high degree of efficiency in the secondary combustion chamber, in the following manner. Firstly, by maintaining an elevated flue gas temperature for a sufficient length of time and secondly, by introducing additional (secondary) combustion air and thoroughly mixing this combustion air with the flue gas. This secondary combustion air maximizes combustion efficiency by oxidizing residual carbon monoxide to carbon dioxide.

The flue gas temperature is maintained by minimizing heat losses and ambient air leaks which may otherwise cool the flue gas prematurely. A seal will limit air in-leakage at the point where the rotating kiln intersects with the stationary wall of the secondary combustion chamber. A quench tank containing cooling water will form the water seal for the opening in the bottom of the secondary combustion chamber through which non-combustible residue from the kiln and fly ash particles from the secondary combustion chamber is removed. The envelope of the secondary combustion chamber is a welded, gas tight steel skin that prevents air leaks and a refractory system comprised of refractory bricks, insulating bricks and internal and external insulation will minimize heat losses through the walls of the secondary combustion chamber.

In general, the secondary combustion chamber provides for vertical flow of flue gas and its volume will be determined by flue gas residence time requirements. The geometric configuration will be confirmed by a series of laboratory flow modelling tests in the detail design phase.

All of the interior surfaces of the secondary combustion chamber will be vertical or steeply sloping and this configuration, together with vertical flow of the flue gas, will minimize the deposit of fly ash in the secondary combustion chamber and provide for separation, by gravity, of some of the larger fly ash particles.

These particles, along with slag from the rotary kiln, will fall through a chute into a water filled quench tank at the bottom of the secondary combustion chamber. The particles will be cooled and solidified in the quench tank.

A secondary combustion air system injects ambient air into the flue gas stream exiting the kiln ensuring a thorough mixing of the flue gas stream and uniting semi-oxidized combustibles with oxygen to assure complete incineration of the wastes and minimizing emissions of carbon monoxide. The air is injected through nozzles perpendicular to the direction of the flue gas flow. These nozzles are located on two opposing sides of the secondary combustion chamber and impart sufficient velocity to

the secondary air for complete penetration of the flue gas stream. This technique provides thorough mixing of the flue gas and ensures complete combustion and consistent temperature, velocity and particle distribution profiles in the flue gas.

Secondary air injection also results in an initial cooling of the flue gas from the maximum temperature attained near the outlet end of the rotary kiln. An excess air ranging from 150% to 170% is normally achieved following secondary air addition.

A typical flue gas temperature profile through the combustion process is illustrated on Figure 16.

Combustion Control

Control of the combustion process is achieved by having knowledge of the heat content and oxidation rate of each waste, and then scheduling the mixing and feeding rate of each waste to the combustion system so that the total heat released is reasonably constant.

The nature and physical form of the waste determines its suitability for control of overall heat release in the system.

- Aqueous liquids and sludges unsuited for control purposes, are injected at predetermined constant rates resulting in a relatively constant release of heat.

- Drummed and other batch fed wastes are introduced at predetermined regular intervals and release additional heat. Because of the nature of the batch feed process, this heat release is not constant and cannot be used for control purposes.

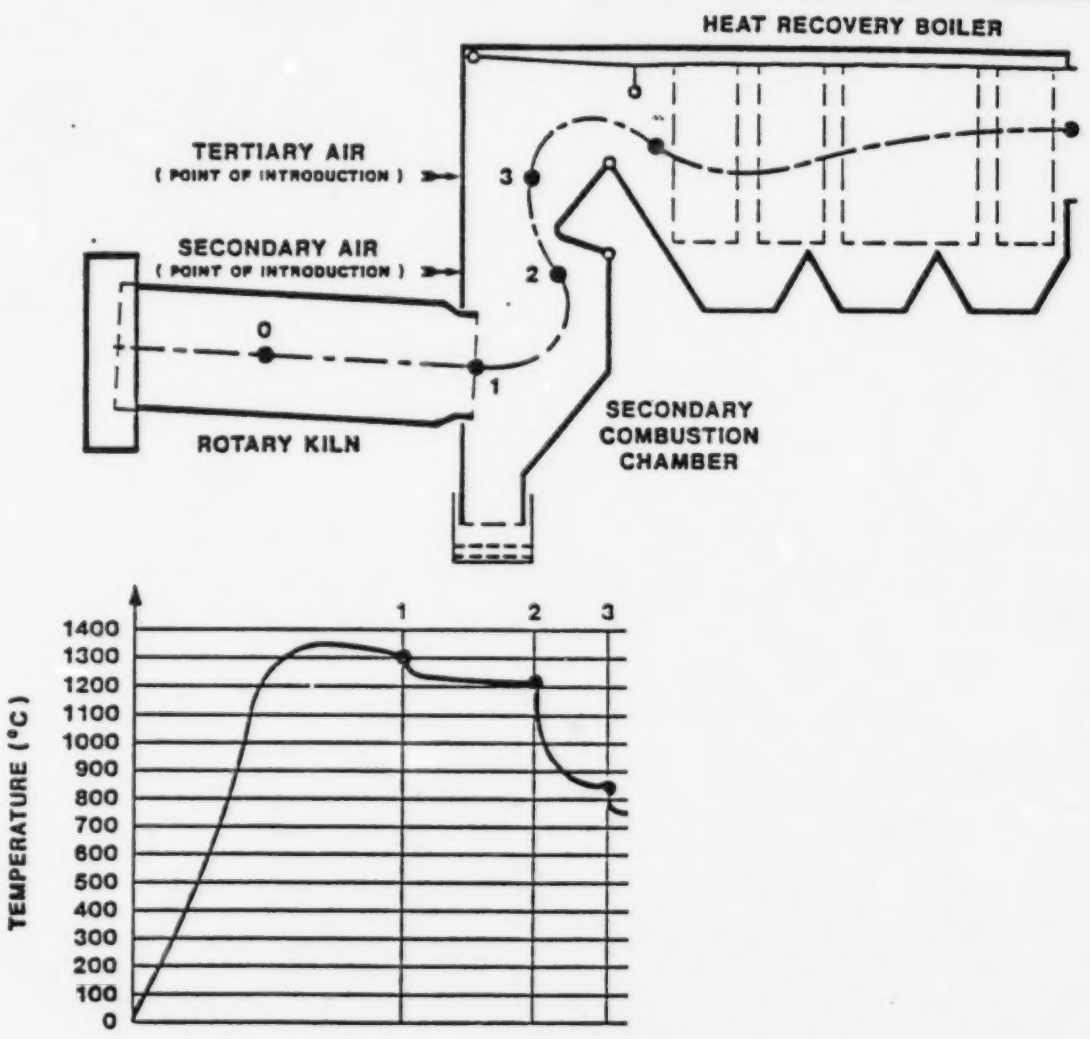


FIGURE 16

VonRoll ENVIRONMENTAL ELEMENTS CORPORATION

OWMC TREATMENT FACILITY

TYPICAL GAS TEMPERATURE PROFILE

M.O. NO.	398012
DRAWING NO.	A13

Therefore, high heat content liquid wastes are injected at controlled feed rates to release additional heat as and when required to even out the total combined heat release in the incinerator. The feed rate can be automatically modulated based on the oxygen content in the flue gas at the outlet of the electrostatic precipitator.

This method of control is illustrated on Figure 17 entitled Typical Kiln Heat Release.

A heat peak caused by batch fed wastes will be permissible if:

- tne peak does not exceed 115% of the design capacity of the kiln,
- the occurrence is infrequent, and
- the duration of the peak is short.

Heat releases in excess of 115% of the maximum capacity of the kiln are avoided by limiting the size of each batch of waste that is fed to the kiln.

The addition of secondary air is adjusted from time to time by the operator located in the control centre, based on his observation of secondary combustion chamber temperatures.

Key Design Parameters

The most important parameters which must be considered in the design of the combustion system for an industrial waste incineration plant of this type, are those dealing with:

- the time interval during which flue gases remain in the high temperature combustion zone,
- the temperature which the flue gases are subjected to,

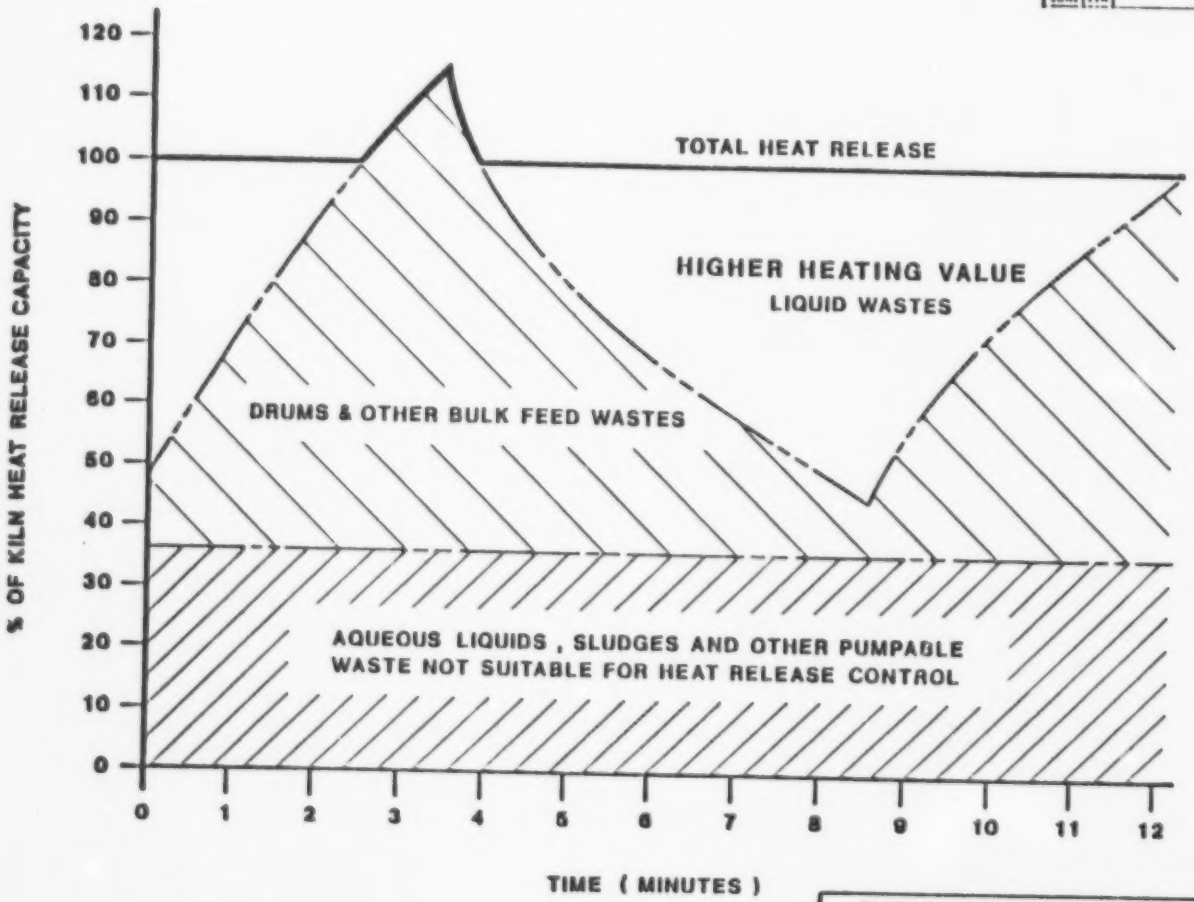


FIGURE 17

VonRoll	ENVIRONMENTAL ELEMENTS CORPORATION
OWMC TREATMENT FACILITY	
TYPICAL KILN HEAT RELEASE	
M.O. NO. 398012	DRAWING NO. A9

- the turbulent conditions created in the combustion zone to facilitate contact between the organic species and oxygen from combustion air, and

- the amount of combustion air and therefore oxygen in the combustion zone.

Evaluation of the flue gas residence time requires consideration of the physical sizing of the rotary kiln and the secondary combustion chamber, the thermal load imposed on the system by the waste feed, the heat losses through the kiln shell and with the discharged slag, and the physical geometry of the system.

The residence time remains fairly constant for a given set of operating conditions since the flue gas volume will not change, as further explained below:

- The primary and secondary combustion air systems are forced air systems and as such, their output is controlled by dampers and represents a known quantity of air being introduced at controlled rates.

- Air leakage into the combustion zone is minimal, typically less than five percent.

- Expansion in the volume of flue gas caused by combustion reactions is compensated for by modulating the flow of flue gas through the induced draft fan in response to static pressure in the secondary combustion chamber.

A residence time of over 2 seconds is generally considered acceptable for the destruction of organics in industrial waste incineration systems of this type. A more detailed presentation of the residence time being proposed for OWMC's incineration system, follows later in this section.

The temperatures of greatest interest are those existing from a point midway down the rotary kiln to a point in the secondary combustion chamber where secondary combustion air is injected into the flue gas. It is in this region that volatilized organic compounds are destroyed thermally. The normal operating range for the temperature of the flue gas in the secondary combustion chamber of the combustion system just prior to secondary air injection is from 1000°C to 1400°C. This temperature remains reasonably constant for a given set of operating conditions since it is closely related to the oxygen content of the flue gas, and the oxygen content is controlled by varying the rate at which high heat content liquid wastes are injected to the rotary kiln, as described earlier in this section.

Turbulence refers to the turbulence of the flue gas in the combustion system including the rotary kiln and secondary combustion chamber. The dynamics of the combustion process in the kiln and the manner in which secondary combustion air is injected into the secondary combustion chamber contributes to the turbulence of the flue gas.

In the case of waste which is highly flammable, incineration takes place in a very short period. This leads to the largest portion of the heat release taking place in a relatively short time in the kiln resulting in incomplete combustion and formation of a reducing atmosphere. Secondary air therefore must be introduced to ensure total burn-out of the flue gases.

Von Roll carefully select the location of secondary air injection nozzles with the aid of flow modelling tests, to optimize secondary combustion chamber configuration and flow patterns. The secondary air system mixes combustion air intensively and turbulently with the volatile constituents and the solid combustibles in the flue gas, and this results in complete burn-out of gases and particles. Air is injected in high velocity jet streams perpendicular to the flow of flue gas in the secondary combustion chamber. The nozzles through which the secondary air is injected are designed to impart sufficient velocity to the secondary

combustion air jet streams so that complete penetration of the flue gas stream is achieved whenever the heat release rate is within the normal operating range.

The system design proposed for OWMC's Facility will incorporate all of the features described to provide the optimum combination of time, temperature, turbulence, and available oxygen while maintaining adequate safety margins to allow for deviations from the optimum, which will occur in practical circumstances on an operating plant.

Figures 18, 19, 20 and 21 illustrate the time-temperature relationships for a range of operating temperatures varying from 1 100°C - 1 400°C in the rotary kiln. It should be noted that the calculation for residence time starts in the centre of the rotary kiln and not, as is often done, at the kiln feed end since maximum gas temperatures are only achieved near the centre of the kiln. All figures represent the condition at full load operation.

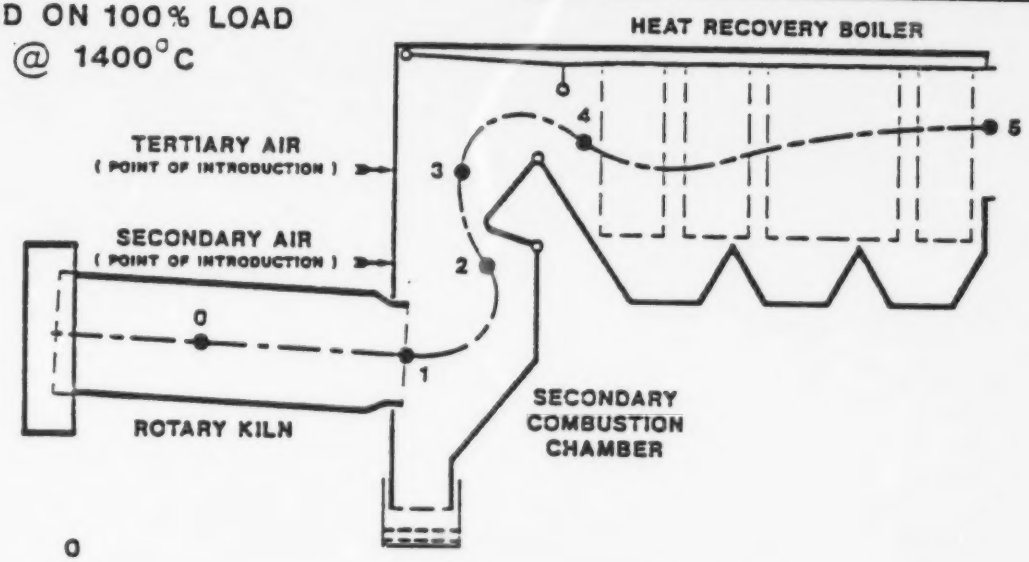
Figures 18 - 21 indicate the following:

- The total residence time in the high temperature zone, calculated from the kiln mid-point up to the secondary air injection nozzles, ranges from 3.5 seconds to 3.1 seconds.

- The total residence time at or above 900°C, calculated from the kiln midpoint up to the tertiary air injection nozzles, ranges from 4.2 seconds to 3.8 seconds.

- The total residence time at or above 750°C, calculated from the kiln midpoint to the boiler inlet, ranges from 5.1 seconds to 4.6 seconds.

BASED ON 100% LOAD
@ 1400°C



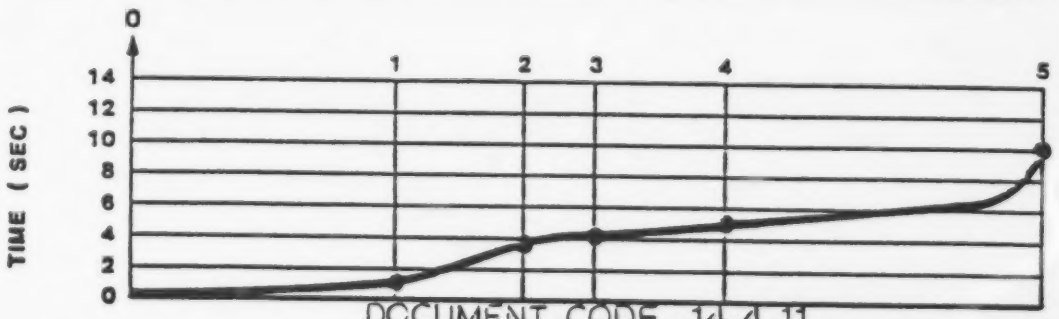


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FIGURE 18

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OWMC TREATMENT FACILITY			
GAS TEMPERATURE AND RESIDENCE TIME			
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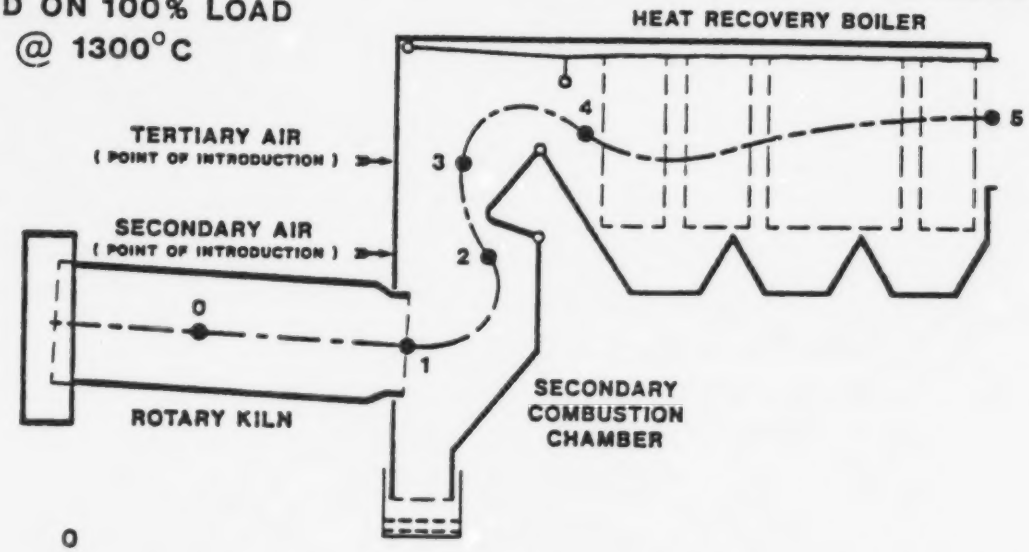
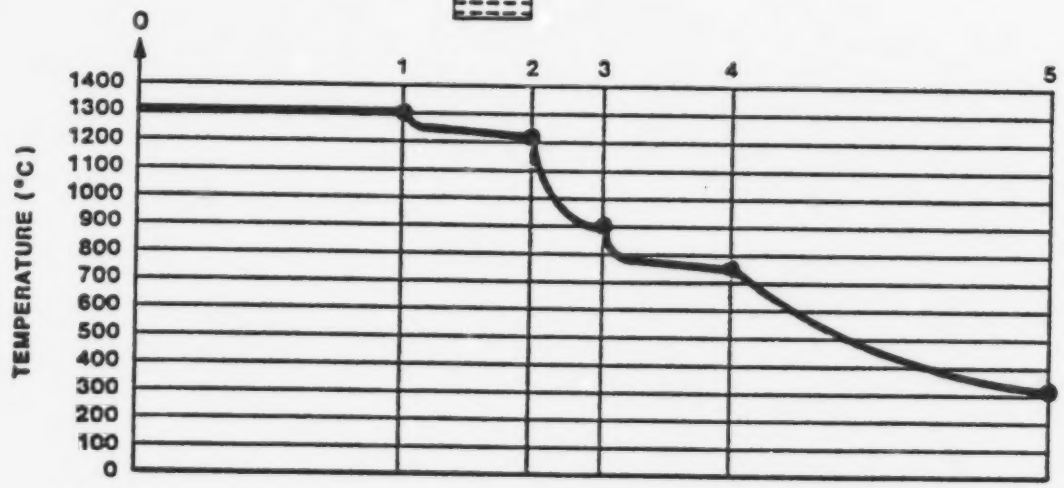
BASED ON 100% LOAD
@ 1300°C





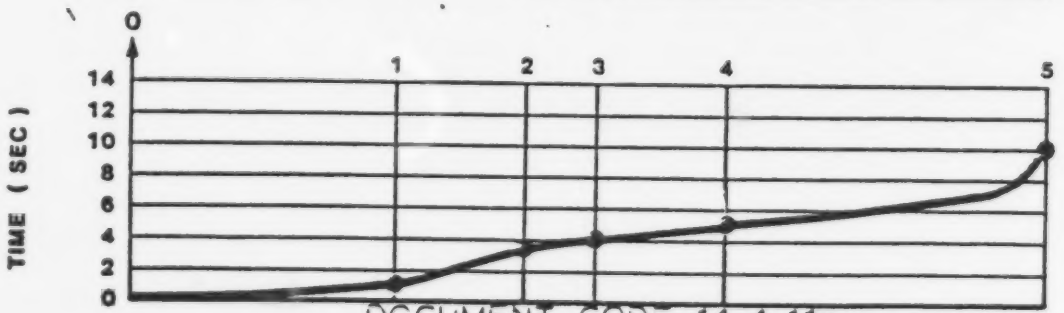


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FIGURE 19

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OWMC TREATMENT FACILITY		
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GAS TEMPERATURE AND RESIDENCE TIME		
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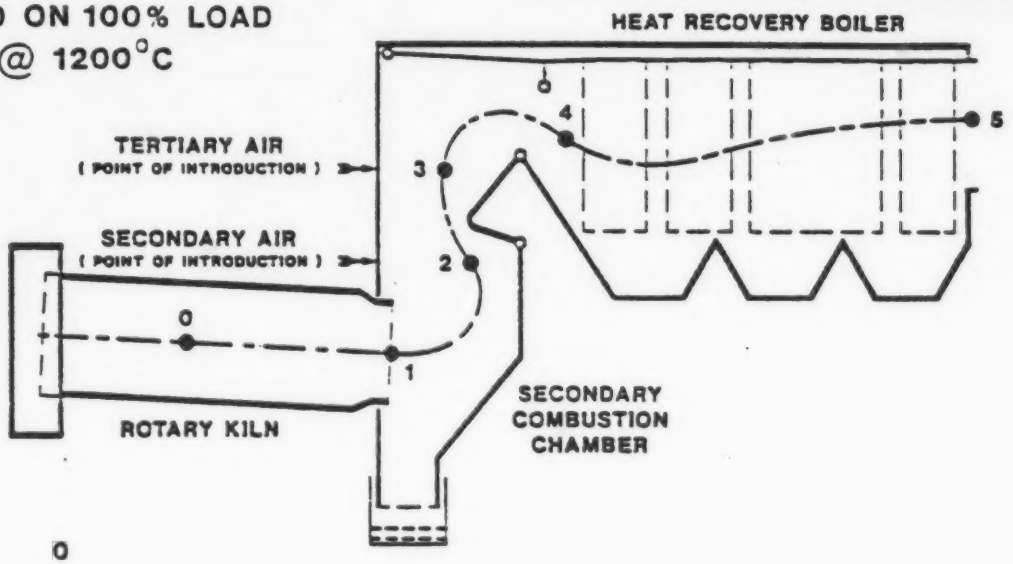
ZONE	LTR	DESCRIPTION	DATE	APPD

BASED ON 100% LOAD
@ 1200°C



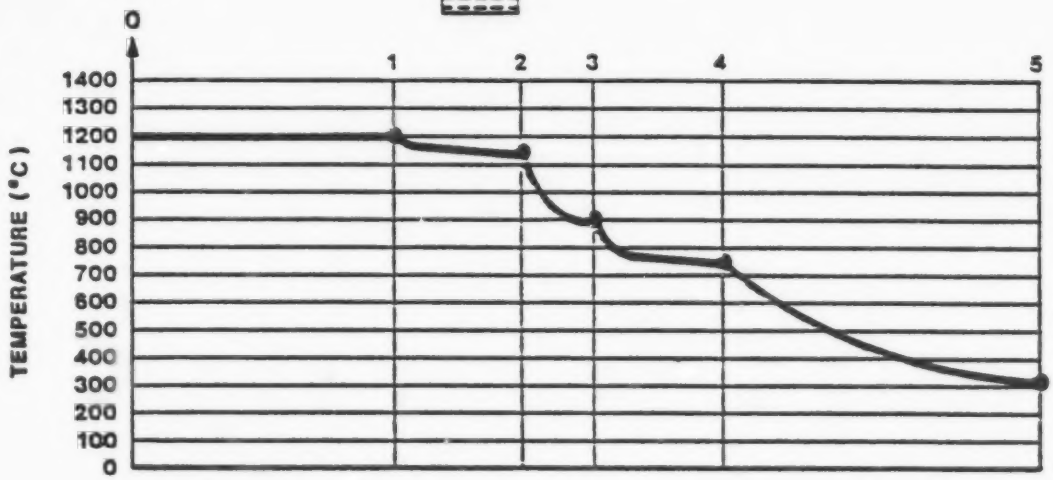
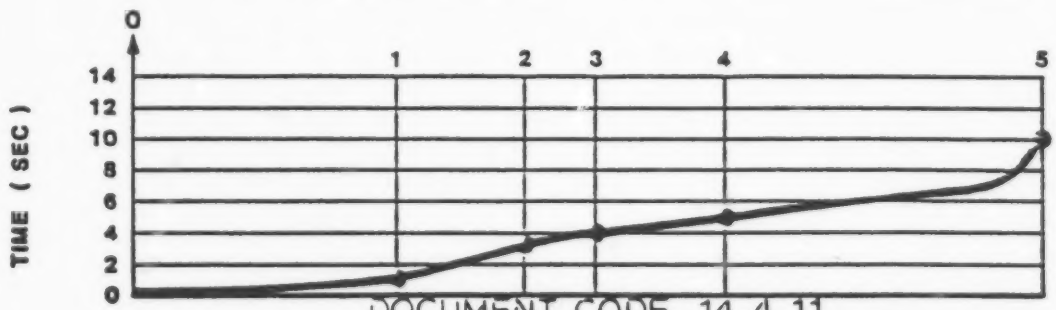


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FIGURE 20

VonRoll ENVIRONMENTAL ELEMENTS CORPORATION

OWMC TREATMENT FACILITY

GAS TEMPERATURE AND RESIDENCE TIME

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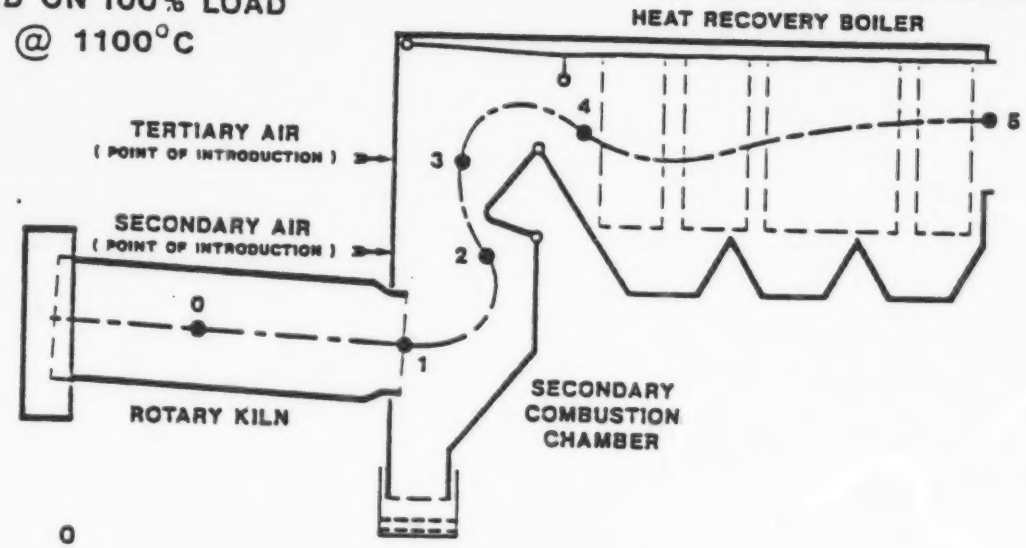
	REVISIONS			398012	A71		

BASED ON 100% LOAD
@ 1100°C



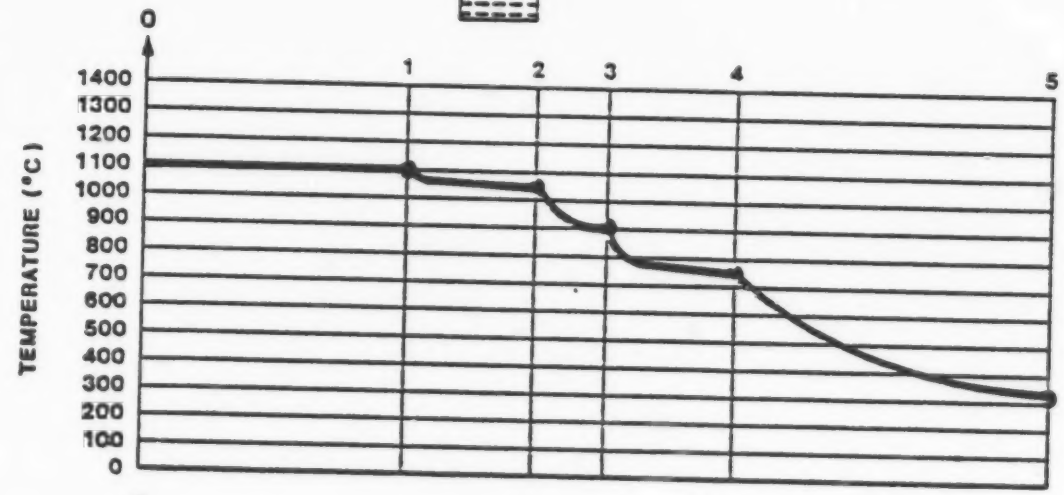
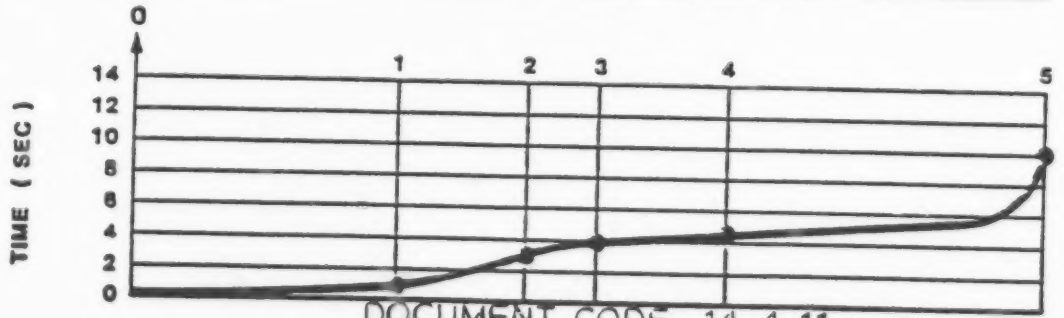


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FIGURE 21

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OWMC TREATMENT FACILITY

GAS TEMPERATURE AND RESIDENCE TIME

DRAWN	CHECKED	APPROVED	APPROVED

LTR	DESCRIPTION	DATE
REVISIONS		

SCALE	W.O. NO.	DRAWING NO.	SHEET	REV.
	398012	A72		

- o In all cases, the residence times are well above the minimum values considered necessary to achieve optimum destruction of organics in installations of this type, thereby providing margins to ensure that the best possible performance is consistently achieved in minimizing organic emissions to the environment.

Combustion System - Flexibility

The combustion system must have flexibility to accept a range of waste types having widely varying physical and chemical characteristics. The flexibility of the proposed design is demonstrated below:

Figure 22, entitled Load Range Diagram for the Rotary Kiln, illustrates the normal operating range of the unit as a function of waste feed rate and average heat content for the combination of wastes entering the kiln at any given time. The Maximum Instantaneous Load is a heat release limitation which, when exceeded, could result in system malfunction. The Maximum Continuous Load is a limitation on the average instantaneous heat release values occuring in a one hour period. No auxiliary fuel will be required for proper operation of the Incineration System at a temperature of 1200°C prior to secondary air addition, providing the heat content and feed rate of the waste are maintained at values that fall within the area marked "Normal Operating Range".

It can be seen that a wide range of operating conditions can be accommodated in normal operation, and that this can be further increased by providing additional energy input to the combustion system in the form of preheated combustion air or by the firing of natural gas in the kiln front wall burner.

The combustion system can be operated down to 50% of the Maximum Continuous Load, although fuel may be required at this condition depending on the heat content of the waste and the required operating temperature.

The system can accommodate wide variations in the amount of non-combustible material introduced to the rotary kiln. Up to 30% by weight

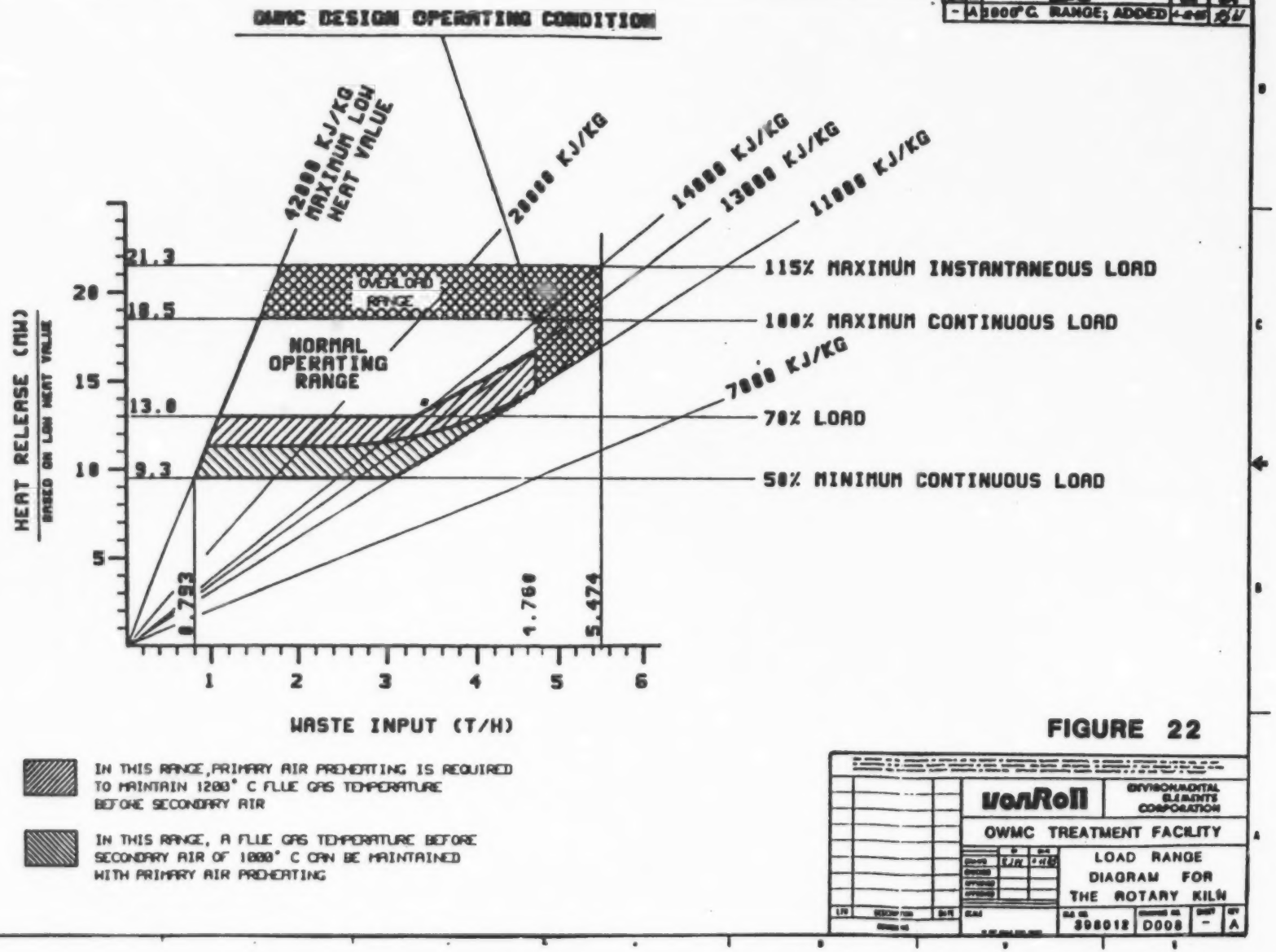

FIGURE 22

von Roll	ENVIRONMENTAL ELEMENTS CORPORATION
OWMC TREATMENT FACILITY	
LOAD RANGE DIAGRAM FOR THE ROTARY KILN	
398012	D008

can be tolerated although less than half this amount is expected in normal operation.

While the physical/chemical treatment plant includes processes to dewater aqueous organic waste, the combustion system can also tolerate up to 50% by weight of water in the waste feed. It is however beneficial to dewater aqueous waste prior to incineration, as this can reduce the auxiliary fuel requirements which may be required if sufficient quantities of high heat content waste are not available.

Considerable flexibility is provided in disposing of wastewater which has low organic content, since the following quantities can be injected to the secondary combustion chamber while maintaining 1200°C temperature prior to the addition of secondary air:

- o 100% Maximum Continuous Heat Load - 1500 kg/h
- o 70% Maximum Continuous Heat Load - 700 kg/h

These quantities are included in the 4760 kg/h of waste fed to the incinerator at maximum load.

Previous paragraphs have addressed the conservative design of the combustion system in terms of flue gas residence time. Flexibility also exists to increase the residence time should this be required to properly incinerate an unusual type of waste. Figure 23 illustrates the manner in which flue gas residence times can be increased by operating the system at reduced loads, 70% load being used for illustration purposes. It will be noted that:

- o The total residence time in the high temperature zone, calculated from kiln midpoint to secondary air injection nozzles, increases to 5.2 seconds from 3.5 seconds residence time at 100% kiln load capacity.

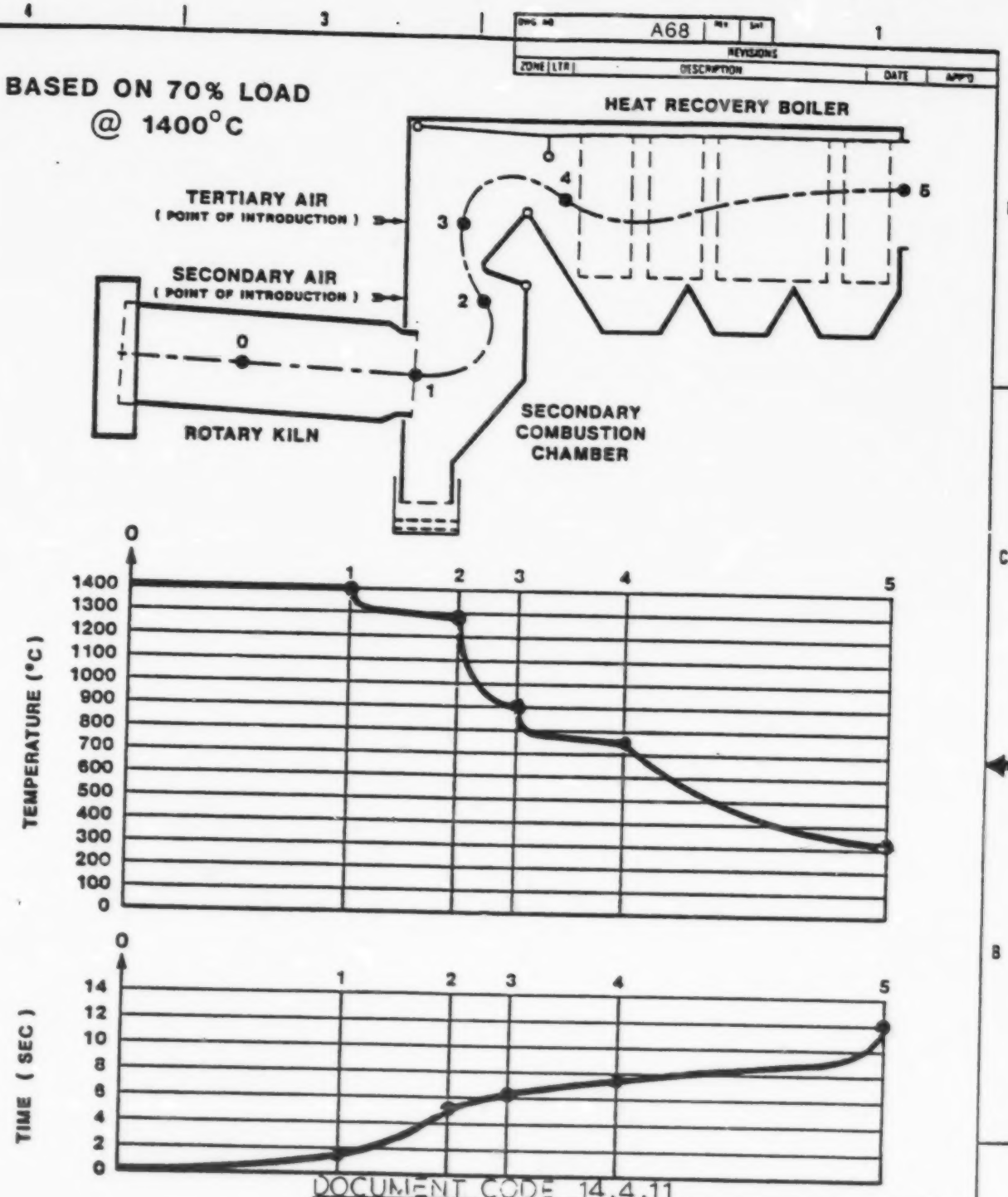

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FIGURE 23

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GAS TEMPERATURE AND RESIDENCE TIME

A68 | 398012

- The total residence time at or above 900°C, calculated from kiln midpoint to tertiary air injection nozzles, increases to 6.2 seconds from 4.2 seconds residence time at 100% kiln load capacity.

- The total residence time at or above 750°C, calculated from kiln midpoint to boiler inlet, increases to 7.5 seconds from 5.1 seconds residence time at 100% kiln load capacity.

Hence it can be seen that the flue gas residence time can be significantly increased by operating the combustion system at reduced loads. Experience on operating installations indicates that this requirement is rarely, if ever, required since the combination of residence times and temperatures presented in Figures 18 - 21 can properly destroy all known organic waste types.

The specific waste type to be incinerated will determine the temperature at which the incineration system will be operated and therefore the time/temperature combination that will result. For example, a waste contaminated with PCBs must be incinerated under US Environmental Protection Agency regulations at 1200°C with a minumum 2 seconds residence time and 3% excess oxygen in the flue gas. In this case the time/temperature combination illustrated on Figure 21 would not be acceptable but that shown on Figure 20 would be acceptable. However, for other more easily incinerated organic waste, the time/temperature combination illustrated on Figure 21 is sufficient to ensure organic destruction.

It is evident from the foregoing discussion, that the combustion system will be designed with sufficient flexibility to ensure that emissions to the environment can be minimized for a wide range of waste types and operating conditions.

4.3.3 FLUE GAS COOLING SYSTEM

The flue gas cooling system proposed for OWMC's Facility consists of a convective type heat recovery boiler preceded by air cooling. This design was recommended by OWMC's Incineration Technology Consultants for the following reasons:

- The Von Roll convective type boiler design has been used successfully in more than twenty-five waste incineration applications. The first boiler of this design was installed in 1971 and has logged in excess of fifty thousand hours of operation. In total, this design has been performing successfully for more than three hundred thousand hours and its field record for reliability is unequalled by any other energy recovery boiler in an application involving the simultaneous incineration of multiple industrial waste streams.

- In Von Roll's experience with both convective and radiant boiler designs, the on-line availability (operating hours/year) achieved with convective boilers is significantly greater than for radiant designs. Radiant boilers experience heavy deposits on the water walls of radiant chambers. These deposits are often firmly fused to the heating surfaces due to the high operating temperatures and require plant shutdown for manual cleaning at 3 - 4 month intervals.

  The demonstrated reliability of the current boiler design is a significant factor in the high number of hours of system availability that can be expected throughout the life of OWMC's incineration process system.

- Where manual cleaning of radiant boiler heating surfaces must be achieved "on-line" through access ports in the boiler casings there is an increased risk to operators which would be preferable to avoid. The convective boiler designs can be automatically cleaned on-line without risk to operators, and complete shutdowns for cleaning can be limited to one, or at most two events each year.

An increase in the frequency of major cleanings is of primary concern because each major cleaning will result in a minimum of one week in lost system availability.

- The increased flue gas volume which results from the addition of cooling air (tertiary air) ahead of the boiler does not result in any increase in the quantity of contaminants discharged to atmosphere from the incineration plant stack.

- Use of a convective heat recovery boiler permits the selection of a lower flue gas inlet temperature to the spray dryer, located in the flue gas treatment system, than would otherwise be possible if a radiant boiler were selected. This provides significant advantages which are described in Section 4.3.4, pg. 163.

Air Cooling

The flue gas must be properly conditioned prior to entering the convective heat recovery boiler. Thorough mixing of the flue gas is accomplished by the addition of tertiary air which cools the flue gas and provides relatively even flue gas velocity, temperature and particulate cross sectional profiles at the boiler inlet. These benefits are critical to maximizing the life and energy production capability of the heat recovery boiler.

Boiler performance is affected adversely by the deposition of molten or plastic fly ash particles on the boiler heat transfer surfaces (tubes). These particles stick to the boiler tubes and cannot be removed by an automatic boiler tube cleaning system. This slagging process is prevented on the proposed design by reducing the temperature of the flue gas below the softening temperature of the fly ash. Boiler performance is also adversely affected by unnecessary or excessive cooling of the flue gas. The tertiary air system is provided to optimize boiler performance by maintaining the temperature of the flue gas at the inlet to the boiler, at a constant level of approximately 750^{o}C.

A fan, duct and nozzle arrangement similar to that used for secondary air injection is provided, with the tertiary air nozzles located on both sides at the top of the secondary combustion chamber. The quantity of tertiary air is automatically regulated based on the measured flue gas temperature at the boiler inlet.

The flue gas cooling system will be designed with sufficient flexibility to modulate the volume of tertiary air injected into the secondary combustion chamber and optimize boiler performance by setting the boiler inlet flue gas temperature as high as possible, without causing pluggage of the waste heat recovery boiler.

Two baffles will be placed in the secondary combustion chamber to help ensure that the flue gas enters the boiler with a relatively consistent velocity profile (see Figure 24). One baffle will be in the shape of a nose and will be located in the back wall of the secondary combustion chamber while the secondary baffle will be formed by sloping the ceiling in the secondary combustion chamber. These baffles will prevent a reduction of the residence time caused by short-circuiting of the flue gas. The exact shape and location of each baffle will be determined by laboratory flow modelling of the secondary combustion chamber.

Heat Recovery Boiler

The boiler design proposed for use in the Incineration System has evolved and been optimized from experience with many incineration system boiler designs. The current design reflects this experience and provides for safety in operation, consistency in steam production and maximum reliability.

Maximizing boiler reliability is largely a function of the following factors:

- The characteristics of the entering flue gas, especially the temperature, velocity and particulate cross sectional profiles. This requirement has been addressed in the previous section dealing with air cooling.

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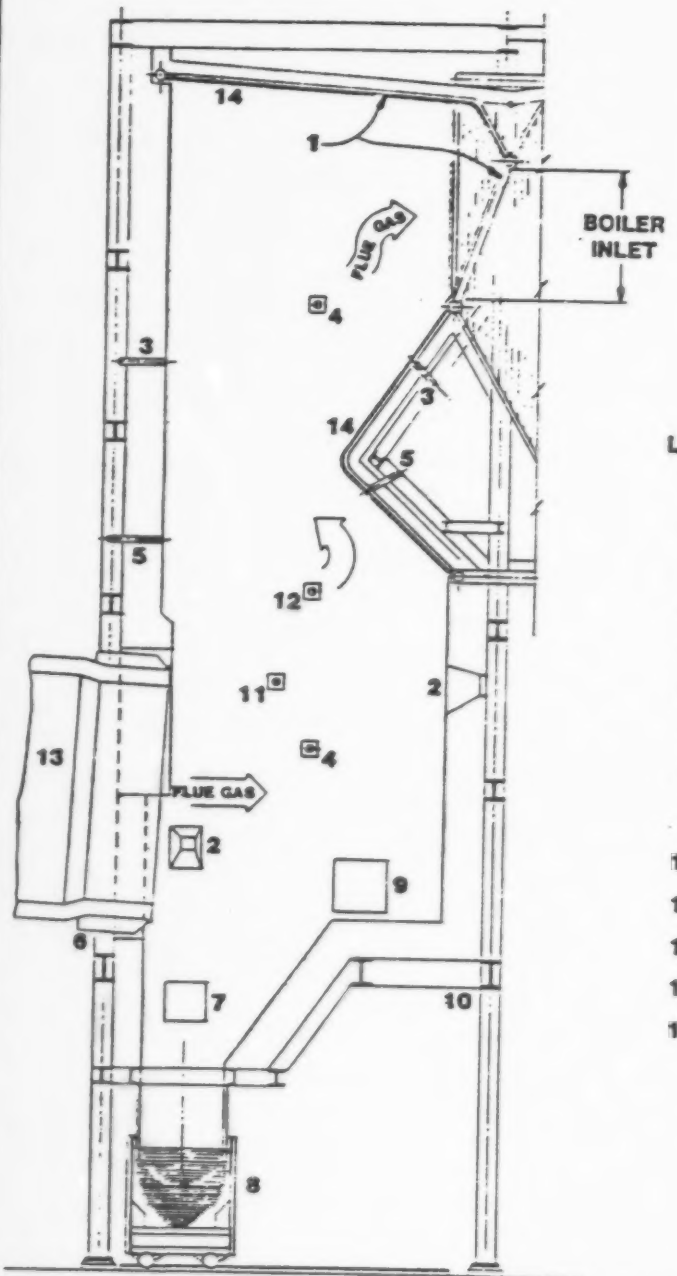
REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APP'D



LEGEND

1. BOILER TUBES
2. SIGHT PORT
3. TERTIARY AIR NOZZLES
4. TEMPERATURE SENSOR
5. SECONDARY AIR NOZZLES
6. AIR COOLED KILN END
7. INSPECTION PORT
8. SLAG CHUTE & QUENCH TANK
9. ACCESS DOOR
10. SUPPORTING STEEL STRUCTURE
11. FLUE GAS SAMPLING PORT
12. PRESSURE SENSOR
13. ROTARY KILN
14. INTERNAL BAFFLES

FIGURE 24

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TYPICAL SECONDARY COMBUSTION CHAMBER WITH BOILER INLET

SCALE	M.S. NO.	DRAWING NO.	SHEET	REV.
	398012	A14		

- Sound boiler design including proper feedwater treatment, effective blowdown, proper design of water and steam flow in the boiler and the arrangement of the various boiler sections.

- Keeping the boiler tubes relatively, but not completely free of fly ash deposits.

- Controlling flue gas temperature to minimize corrosion and controlling flue gas velocity to minimize erosion of the boiler tubes.

The waste heat recovery boiler will incorporate the features of horizontal flow of flue gas in the evaporator section and will provide for natural circulation of steam and boiler water. The boiler will contain three evaporator sections and two superheater sections. Vertical tube sections will be constructed as illustrated on Figure 25 and will be connected to two water headers running longitudinally along the boiler and the boiler drum running perpendicular to the longitudinal axis of the boiler. The side walls and roof of the horizontal portion of the boiler will be constructed from finned tubes welded together to form a gas-tight box. The refractory-lined baffles of the secondary combustion chamber will be integral with the boiler evaporator sections. A cross sectional view of the boiler and secondary combustion chamber is presented in Figure 26.

Approximately sixty percent of the heat generated by the incineration of waste will be recovered and converted into usable energy in the form of steam, as shown on the illustrative energy balance, Figure 27.

A mechanical rapping mechanism will be provided for cleaning the horizontal gas flow section of the boiler during normal operation. This mechanism will vibrate each individual tube bundle at predetermined intervals. The bottom cross headers of the boiler tube banks are arranged to allow large flakes or sheets of fly ash removed during rapping to fall unobstructed into the boiler hoppers. Use of a mechanical rapping system rather than soot blowers provides the following advantages:

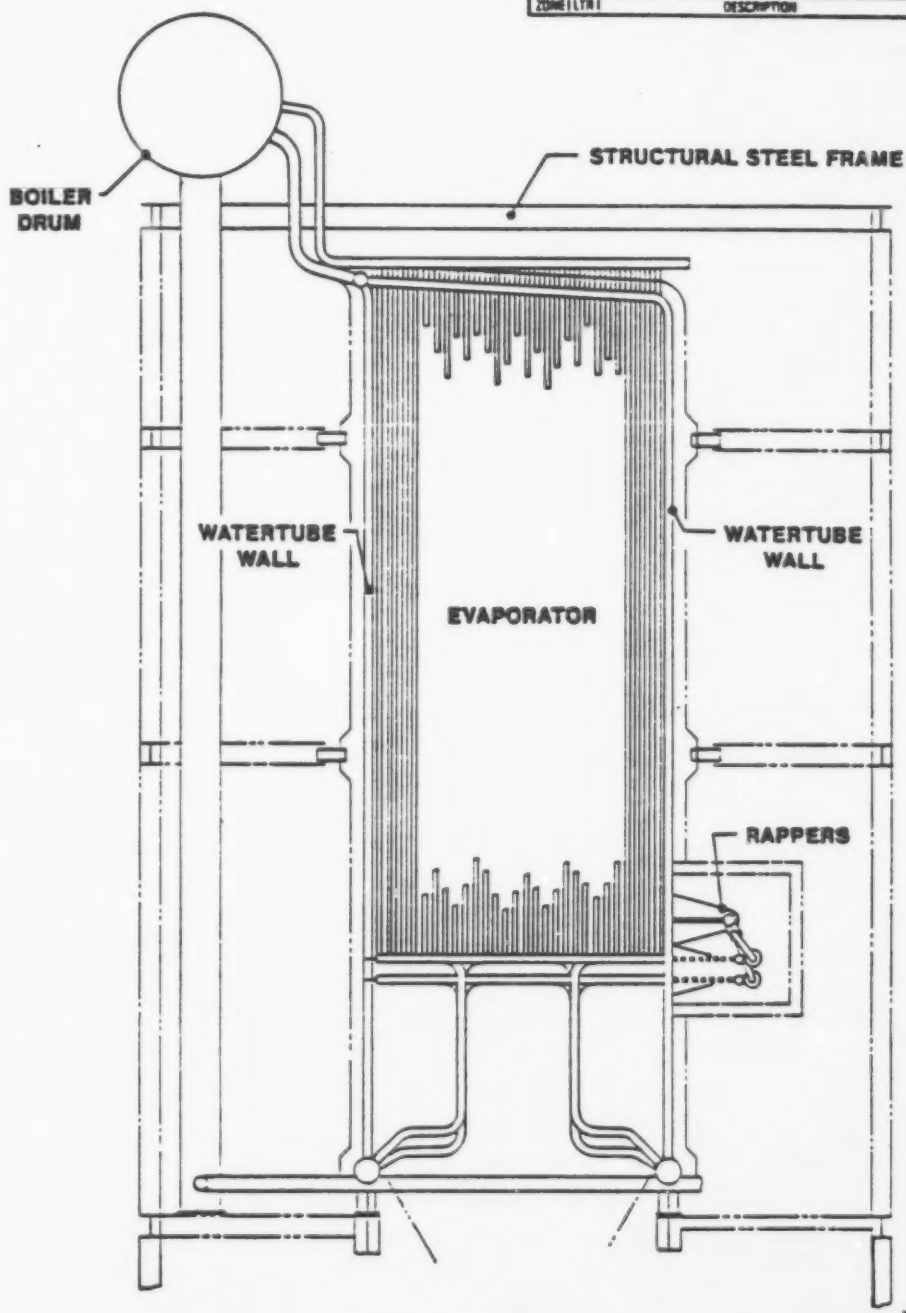

FIGURE 25

VonRoll ENVIRONMENTAL ELEMENTS CORPORATION

OWMC TREATMENT FACILITY

TYPICAL EVAPORATOR SECTION OF BOILER

DRAWN	CHECKED	APPROVED	APPROVED

SCALE	M.B. NO.	DRAWING NO.	SHEET	REV.
	398012	A19		

DWG. NO.	A18	REV	SHT

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APPD

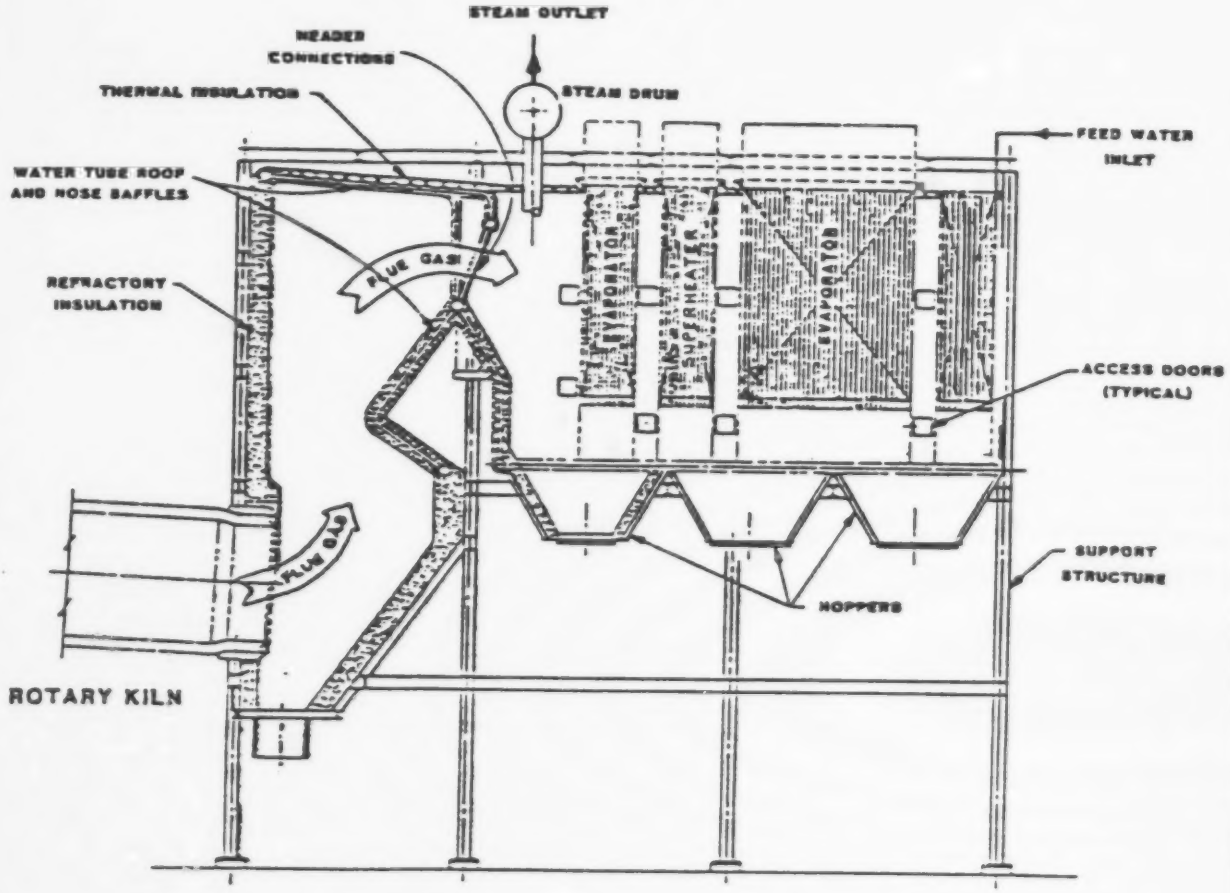

FIGURE 26

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OWMC TREATMENT FACILITY

	BY	DATE
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APPROVED		
APPROVED		

TYPICAL SECONDARY COMBUSTION CHAMBER AND TAIL END BOILER

SCALE	M.O. NO.	DRAWING NO.	SHEET	REV.
	398012	A18		

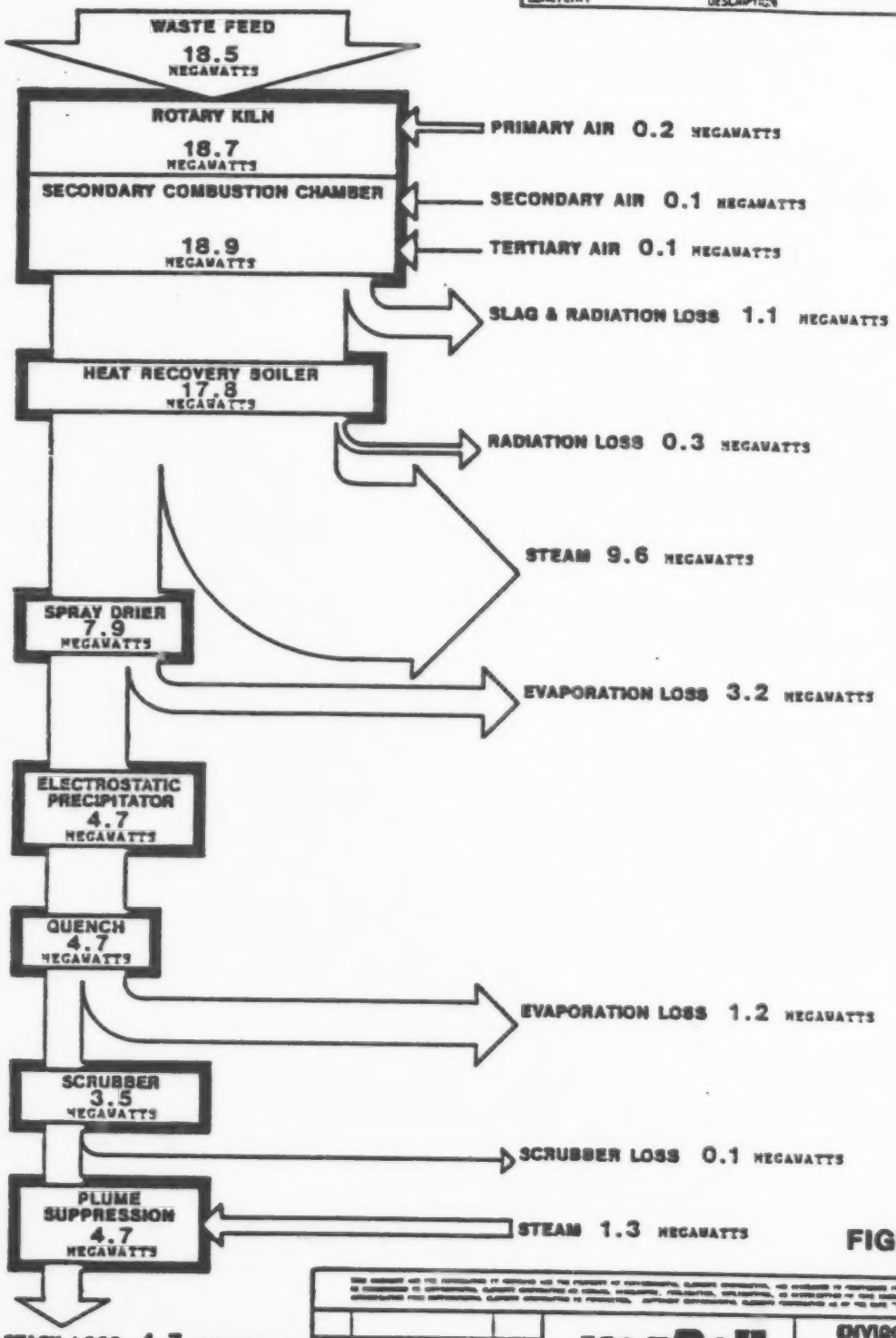

FIGURE 27

vonRoll	ENVIRONMENTAL ELEMENTS CORPORATION		
OWMC TREATMENT FACILITY			
DRAWN		1-31-95	INCINERATION SYSTEM ENERGY BALANCE
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APPROVED			
APPROVED			
SCALE	M.E. NO. 398012	DRAWING NO. A20	SHEET

- o Mechanical design is simple.
- o Abrasion is avoided on the tubes closest to the soot blowers.
- o A thin protective layer of ash is left on the tubes.
- o Less re-entrainment occurs during cleaning.

An arrangement of a typical tube bundle showing the location of the rapping mechanism, is illustrated on Figure 25.

Two types of corrosion must be eliminated to achieve high boiler reliability. The first type is due to the condensing of corrosive substances in the flue gas on the boiler tube wall and it occurs when the temperature of the exterior surface of the boiler tube wall falls below approximately 160°C. The evaporator section of the boiler is protected by:

- o maintaining a tube temperature above 160°C, and
- o designing the boiler for a flue gas exit temperature greater than 250°C.

The second type of corrosion is due to the high temperature environment in which highly corrosive substances in the fly ash attack the tubes. This type of corrosion becomes a significant factor with waste containing certain metals and/or halogens and at exterior tube wall surface temperatures above approximately 370°C. Designing the boiler to limit these types of corrosion requires evaluation of the chemical composition of flue gas and fly ash particles.

Figure 28 illustrates the relationship between boiler tube wall temperature and the rate of corrosion.

The boiler saturation temperature and final steam conditions for OWMC's incineration plant have been determined with this information in mind and the final steam temperature has been limited to 300°C. The flue gas temperature at the boiler exit has been selected at 325°C, based on the requirements of the flue gas treatment system.

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ZONE	LTR	DESCRIPTION	DATE	APP'D

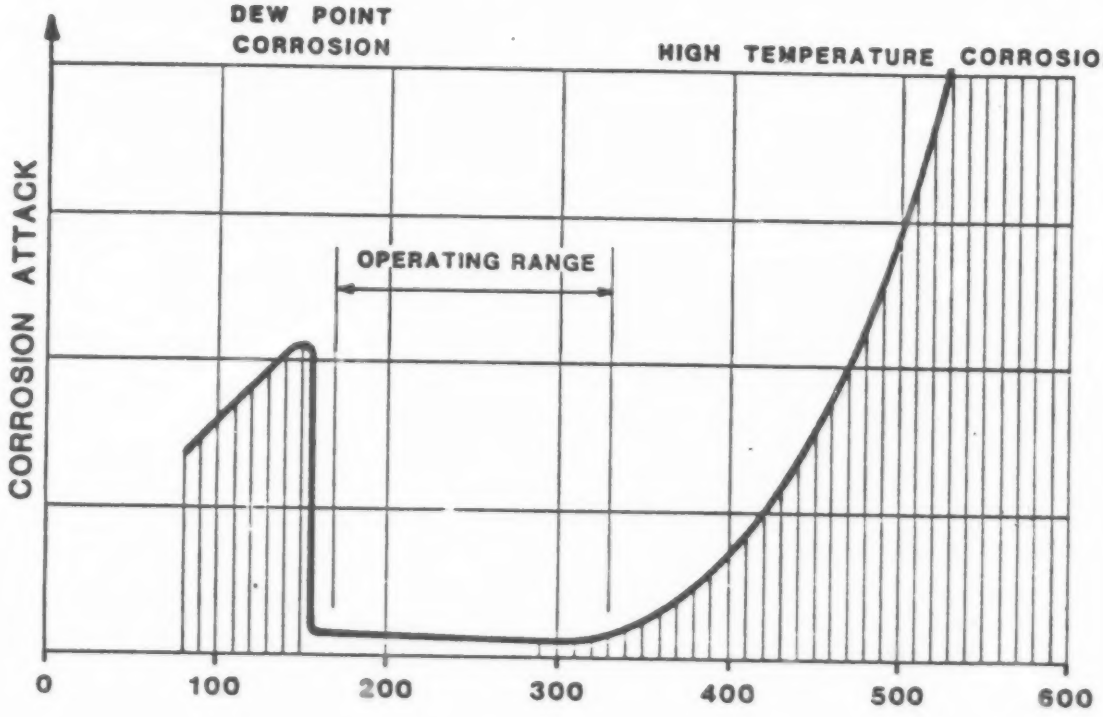

FIGURE 28

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OWMC TREATMENT FACILITY

	BY	DATE
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APPROVED		

CARBON STEEL CORROSION RATE AS A FUNCTION OF TEMPERATURE

LTR	DESCRIPTION	DATE
REVISIONS		

SCALE

W.O. NO. 398012

DRAWING NO. A15

SHEET

REV.

Final steam conditions of 2750 kPa and 300°C were selected since these represent the highest pressure and temperature conditions that have been satisfactorily demonstrated over many years of operation at a similar facility as further discussed in Section 4.3.9 (pg. 193). The steam generation conditions of the waste heat recovery boiler will be reviewed and finalized during detailed engineering.

Another factor affecting boiler performance is the velocity of flue gas in the boiler. An average flue gas velocity of approximately 4 m/s provides the optimum conditions for:

- minimizing erosion of the boiler tubes,
- allowing for flyash removed during tube rapping to fall into hoppers beneath the boiler without significant amounts being re-entrained in the flue gas, while
- still maintaining reasonable heat transfer rates required for economic boiler sizing.

This relatively low velocity will also provide for greater fly ash removal in the boiler and improved performance of the flue gas cleaning system.

Another factor affecting boiler performance is the control of the combustion system to achieve reasonably consistent gas conditions at the boiler inlet. This matter was addressed in Section 4.3.2, (pg. 127).

4.3.4 FLUE GAS TREATMENT SYSTEM

Chapter 3 described the rationale for selecting a flue gas treatment system comprising a spray dryer/reactor, an electrostatic precipitator and a three stage wet scrubber. A number of opportunities were identified to avoid discharging excess liquid effluent for treatment when incinerating wastes having high chlorine and sulphur content, including:

- o the use of a convective heat recovery boiler rather than a radiant type, thereby increasing the thermal capacity of the spray dryer,

- o operating the wet scrubber at higher concentrations of total dissolved solids, thereby reducing the quantity of liquid effluent to be discharged, and

- o operating the system as a two stage scrubbing system by injecting a reagent into the spray dryer/reactor, thereby reducing the load on the wet scrubber and the quantity of effluent to be disposed.

Two-stage scrubbing was adopted for evaluation purposes in Chapter 3 (pg. 67).

A further option identified during the sensitivity analysis (pg. 97), was for the electrostatic precipitator to be replaced by a fabric filter.

Review of Technology Assessment by OWMC's Incineration Technology Consultants

OWMC's Incineration Technology Consultants (ITC) reviewed the technology evaluation described in Chapter 3 of this report and agreed with Monenco's conclusions.

However, they made the following additional comments on the selected flue gas treatment system described as Alternative 4 in the technology assessment, based on their experience as designers and operators of similar facilities together with additional information obtained from equipment suppliers.

- o A convective type heat recovery boiler was preferred rather than the radiant boiler type included in Alternative 4. The rationale for selecting a convective boiler type is presented in Section 4.3.3, pg. 151. The adoption of this boiler type enables the required thermal (evaporative) capacity of the spray dryer to be achieved with a lower flue gas inlet temperature than would otherwise be possible.

- A lower flue gas inlet temperature to the spray dryer was preferred since it would be advantageous, from a maintenance standpoint, to avoid the use of refractory in the spray dryer and a reduced temperature would also eliminate concerns regarding the re-evaporation of heavy metals. While some evaporation of heavy metals will always occur in systems of this type, higher inlet temperatures will evaporate significantly more heavy metals and therefore require the scrubber to have a higher collection efficiency for small particulates. This would result in higher investment and operating costs due to the required increase in pressure loss across the scrubber, and potentially higher releases to the environment.

- While a preference was indicated to reduce the flue gas temperature into the spray dryer below the 525°C figure used by Monenco in the technology assessment, it was recognized that a lower limit also exists for a number of reasons:

  - A minimum temperature is required to assure complete evaporation of the scrubber effluent to be disposed.
  - Also, certain metal salt compounds can become sticky and cause problems in the gas inlet vanes if the temperature is below approximately 325°C.

  Hence, it was concluded that an inlet temperature in the 325°C - 375°C range would be the optimum from a combination of performance in minimizing residual contaminant emissions to the environment, while at the same time minimizing potential operational and maintenance problems.

- The assumed total solids concentrations for lime slurry and scrubber effluent were considered very conservative at 15% by weight hydrated lime ($Ca(OH)_2$) and 10% by weight respectively. Concentrations of 25% by weight ($Ca(OH)_2$) for lime slurry and 11.5% by weight average, ranging up to 20.5% by weight maximum, for

neutralized scrubber effluent to the spray dryer were considered acceptable for the type of scrubber envisaged by the ITC.

- o While semi-dry lime scrubbing systems and "zero-effluent" wet scrubbing systems are both well proven on industrial waste incineration facilities (Ref: Moller et. al.[38], Scharsach[17]), nowhere have the two systems been combined. Concerns were expressed that the addition of the lime slurry to the scrubber effluent would precipitate gypsum with resultant operational problems, plugging of lines etc. While Monenco had recognized this potential problem by proposing to introduce scrubber effluent and reagent to the spray dryer separately, the ITC recommended against adopting such a system since:

  - the system had not in their view been satisfactorily proven,
  - separate injection of reagent and scrubber effluent to the spray dryer would require the use of fixed nozzle, dual fluid nozzles (compressed air and effluent),
  - rotating disc atomizers rather than dual fluid nozzles are recommended as much greater experience exists with such systems, and
  - carryover of lime reagent through the electrostatic precipitator could result in gypsum formation in the wet scrubber, with consequential operating problems.

  The ITC therefore preferred a combination of the alternative opportunities identified by Monenco, use of a convective boiler type and operation of the wet scrubber at higher liquor solids content, rather than two-stage scrubbing in order to achieve a "zero effluent" system even when incinerating wastes having high chlorine and sulphur content.

- o Use of a fabric filter in lieu of an electrostatic precipitator was rejected by the ITC, since it was believed that the uncertainties identified in the sensitivity analysis (Section 3.7.2, pg. 99) outweigh the potential benefits. In particular, a fabric filter

has not been previously used to collect the hygroscopic residues resulting from evaporation of scrubber effluent, and major concerns exist regarding the potential for rapid blinding of filter cloths.

Selected Flue Gas Treatment System

The Incineration Technology Consultants established a flue gas treatment system design incorporating their comments as described in the preceeding paragraphs. The resultant system is described in Section 4.2.4, pg. 113. The system consists of:

- a spray dryer for the disposal of scrubber effluent,
- a two field electrostatic precipitator for the removal of flyash and salt produced by the evaporation of scrubber effluent, and
- a three stage wet scrubber for the removal of acid gases and fine particulates which are subsequently removed from the system as a dry residue in the electrostatic precipitator. A set of chevron type mist eliminators is included after each stage.

Two additional changes were made to the conceptual design established for technology assessment. Firstly, the ITC considered that the exit temperature from the spray dryer could be reduced from 180°C to 160°C, without increasing risks of corrosion in the electrostatic precipitator. Secondly, while the flue gas treatment system was still designed to achieve required performance objectives when incinerating waste having up to 15% chlorine and 3% sulphur content, it was determined that a spray dryer having inlet and outlet temperatures of 325°C and 160°C respectively could only dispose all of the scrubber effluent up to a waste chlorine content of 11.5% and a sulphur content of 1.5%. Peak chlorine and sulphur contents above these values can be tolerated for a maximum period of approximately seven hours, beyond which some scrubber effluent may have to be discharged to the physical/chemical treatment plant to avoid buildup of dissolved solids concentrations above acceptable levels in the scrubber liquor. This possibility is considered unlikely, however, since peaks are by definition of short duration (i.e. less than 7 hours) and the ability to blend waste

feed to the kiln provides considerable control over the chlorine and sulfur content in the waste feed. The evaporative capacity of the spray dryer will increase when the boiler is operating in a partially "dirty" condition i.e. with some deposits on the tubes. Under these circumstances the flue gas temperature at the spray dryer inlet is expected to increase by up to 50°C.

The foregoing was accepted by OWMC since it is not considered a severe operating constraint, recognizing that the average waste chlorine and sulphur content are expected to be in the order of 5% and 1% respectively. Preference was given to a well proven operational system which had demonstrated capability in minimizing residual contaminant discharges to the environment, even if this was at the expense of some operational flexibility.

The expected maximum emissions from this treatment system, prior to final optimization of the system design, are presented on Table 3.

Optimization of Selected Flue Gas Treatment System

The key contaminants which were considered in the optimization were total particulates, fine particulates and aerosols (essentially heavy metal compounds), hydrogen chloride (HCl), hydrogen fluoride (HF)and sulphur dioxide (SO_2).

When optimizing the system's performance, the type of equipment used to control each contaminant must first be identified as follows:

TABLE 3

MAXIMUM EXPECTED FLUE GAS EMISSIONS
PRIOR TO SYSTEM OPTIMIZATION

Contaminant	Emission mg/Nm^3 dry, corrected to 50 percent excess air
Particulates	50
Hydrogen Chloride (HCl)	50
Hydrogen Fluoride (HF)	5
Sulphur Dioxide (SO_2)	200
Nitrogen Oxides (NO_x)	200
Carbon Monoxide (CO)	250
$C_{organic}$ [7]	30
Metals	
Total Class I [6]	0.3
Mercury (Hg)	
Cadmium (Cd)	
Thallium (Tl)	
Total Class II [6]	1.4
Arsenic (As)	
Chromium (Cr)	
Cobalt (Co)	
Nickel (Ni)	
Selenium (Se)	
Tellurium (Te)	
Total Class III [6]	7.0
Antimony (Sb)	
Lead (Pb)	
Cyanide (CN)	
Copper (Cu)	
Manganese (Mn)	
Vanadium (V)	

Note:

1. NO_x, CO and $C_{organic}$ emissions are products of combustion with CO and $C_{organic}$ indicating the efficiency of the incineration process.
2. Short term peaks of CO may be up to 5 times the average value stated.
3. Anticipated maximum emissions of metals are not based on a specific metal content of the waste feed, but rather based on the Incineration Technology Consultants experience with similar operating installations.

TABLE 3 (Cont'd)

MAXIMUM EXPECTED FLUE GAS EMISSIONS
PRIOR TO SYSTEM OPTIMIZATION

4. Emissions are expressed on the same basis as German Regulations (Ref: TA Luft[43]) wherein:

   - values are 24 hour averages.
   - 97% of half hour averages must not exceed the 24 hour average by more than 20%.
   - none of the 1/2 hour averages shall exceed the 24 hour average by more than a factor of two.

5. All values corrected to 50% excess air, (7% O_2) dry and at $0^{o}C$ and 760 mm mercury.

6. Metal classes and the emission values for them are in accordance with German Regulations(Ref: TA Luft[43]).

7. Organic carbon as determined by the Flame Ionization Detection method.

Contaminant	Technology/Equipment
Particulates	Electrostatic Precipitator, Ring-Jets™
Fine Particulates (Aerosols)	Electrostatic Precipitator, Ring-Jets™
Hydrogen Chloride & Hydrogen Fluoride	Packed Bed
Sulphur Dioxide	Ring-Jets (Caustic Soda Reagent)
Mist Entrainment	Mist Eliminators
Liquid Discharge	Spray Dryer

The next step is to understand how each item of technology/equipment functions, and thereby determine what can be done to improve performance.

Spray Dryer (Figure 29)

The purpose of the spray dryer is to atomize the scrubber effluent and mix it with the hot flue gases in such a manner that all free water is evaporated. Evaporation of the water results in a dry, free flowing powder and at the same time cools the flue gas to 160°C. This process is controlled by the droplet size distribution and the method used to mix the atomized mist and hot flue gas. Both the droplet size and mixing are determined by the type of atomizer used. The only two acceptable types of atomizers are rotary atomizer and alternatively, dual fluid nozzles (compressed air and liquid effluent).

The rotary atomizer has been selected for the following reasons:

- Narrower droplet size distribution which provides more reliable evaporation.
- Control of droplet size distribution by variation of rotational speed.
- Finer atomization of slurries (smaller droplets).

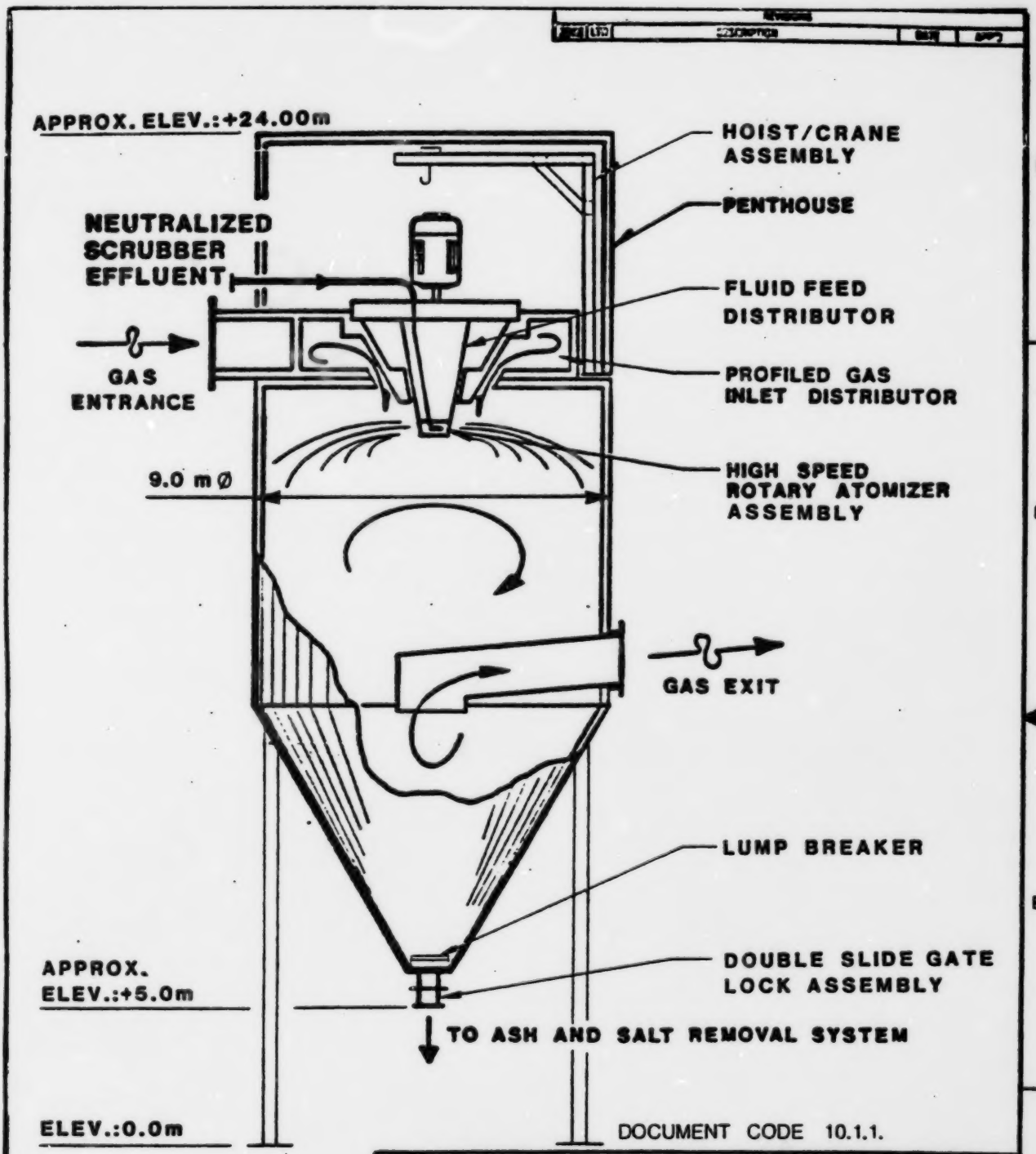
APPROX. ELEV.:+24.00m
HOIST/CRANE ASSEMBLY
PENTHOUSE
NEUTRALIZED SCRUBBER EFFLUENT
FLUID FEED DISTRIBUTOR
GAS ENTRANCE
PROFILED GAS INLET DISTRIBUTOR
9.0 m Ø
HIGH SPEED ROTARY ATOMIZER ASSEMBLY
GAS EXIT
LUMP BREAKER
APPROX. ELEV.:+5.0m
DOUBLE SLIDE GATE LOCK ASSEMBLY
TO ASH AND SALT REMOVAL SYSTEM
ELEV.:0.0m
DOCUMENT CODE 10.1.1.
VonRoll
ENVIRONMENTAL ELEMENTS CORPORATION
OWMC TREATMENT FACILITY
TYPICAL SPRAY DRYER
398012
A173

FIGURE 29

- Better resistance to abrasion. With dual fluid nozzles, abrasive wear changes the nozzle shape and affects the droplet size distribution generated.

- Better atomization control at part loads.

- The rotary atomizer is proven in this application. Dual fluid atomizers are proven in other applications, but not on industrial waste incineration systems.

Electrostatic Precipitator

The electrostatic precipitator is the principle means by which solids are removed from the system. If the solids are not removed the first time through the system, most will be caught in the downstream scrubber and returned to the spray dryer where they will be entrained in the flue gas and returned to the precipitator. Therefore, increasing the removal efficiency of the precipitator may not result in a corresponding decrease in stack emissions. However, it will result in a reduced loading to the downstream scrubber, which will result in less maintenance and improved overall operation.

The present incineration system at the HIM facility in Biebesheim, West Germany, employs a mechanical cyclone instead of an electrostatic precipitator. The cyclone has a particulate removal efficiency of approximately 70%, which results in a heavy dust loading to the scrubber. Von Roll propose to use an electrostatic precipitator having an efficiency of about 90% on future installations of this type, since this will improve scrubber operation and overall system performance.

In considering the benefits that could result by increasing precipitation efficiency above 90%, it is necessary to understand the collection efficiency of different sized precipitators for each particle size. Figure 30 is a plot of data calculated from a mathematical model and should not be confused with actual test data. It shows that all precipitators have their lowest collection efficiencies in the range of 0.3 to 2 microns, with the lowest efficiency at approximately 0.7 to 0.9

A78

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APP'D

PRECIPITATOR FRACTIONAL COLLECTION EFFICIENCY

VS PARTICLE SIZE

VS OVERALL PRECIPITATOR EFFICIENCY

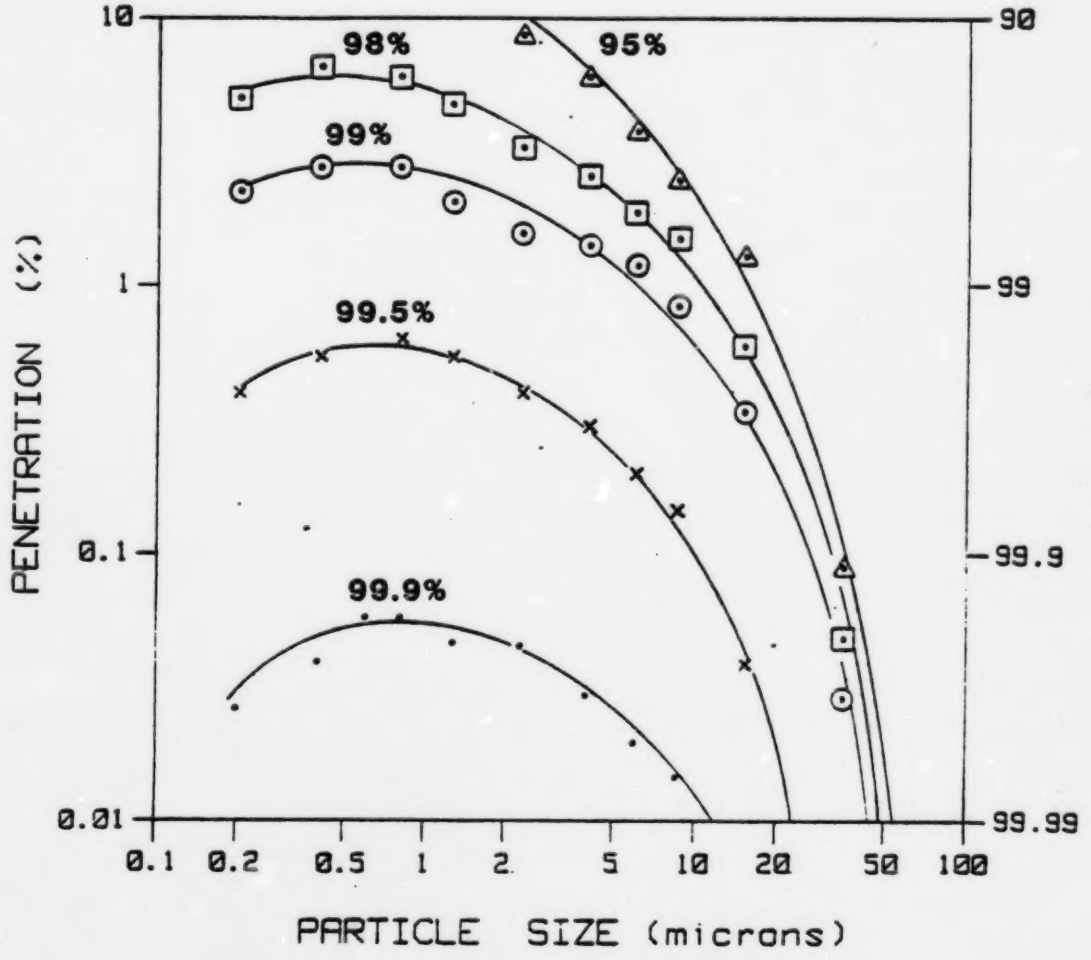

FIGURE 30

	VerRoll	ENVIRONMENTAL ELEMENTS CORPORATION	
	OWMC TREATMENT FACILITY		
	DRAWN DCP 5-4-95	PRECIPITATOR FRACTIONAL COLLECTION EFFICIENCY	
	CHECKED PJM 11-22-95		
	APPROVED TB 12/12/95		
	APPROVED		
LTR / DESCRIPTION / DATE REVISIONS	SCALE	W.O. NO. 398012	DRAWING NO. A78 / SHEET / REV.

microns. This is exactly the size ranges that are enriched with heavy metals in industrial waste incineration systems.

Also, as overall precipitator collection efficiency increases, the collection efficiency in the "fine particle" size range also increases. In terms of the proposed flue gas cleaning system, the effect of this is to reduce the number of times a small particle circulates through the system before it is removed and more importantly, results in a reduction in the amount of particulate material released to the environment.

In addition to overall efficiency, the question of reliability must be reviewed. The selected design includes a two field precipitator with an efficiency of 90%. However, three fields will provide a higher degree of reliability since if one field "breaks down" in a two field unit, half of the precipitator is out of service whereas if one field fails in a three field unit, only one third of the precipitator is out of service. Furthermore, as the precipitator efficiency approaches 98 to 99%, a two field unit is eliminated for mechanical reasons. Therefore, all precipitators in this evaluation with an efficiency of 95% or higher are three field units.

Another feature in precipitator design which affects reliability is the type of high voltage discharge electrode used. The most reliable designs currently utilize either a "rigid electrode" or a "rigid frame". Both of these have replaced the older "weighted wire" design which were prone to breakage. Therefore,either "rigid electrode" or "rigid frame" discharge electrodes will be used for OWMC's Facility.

Finally, as precipitator efficiency increases, so does size and cost. Figure 31 illustrates the relationship between cost and efficiency for a typical electrostatic precipitator on an industrial waste incineration system. This illustrates that the electrostatic precipitator cost rises exponentially as the efficiency approaches 100%. In fact, a precipitator cannot be designed for a theoretical efficiency of 100% and therefore precipitator cost is asymptotic to the line passing through the 100% point on the graph.

REVISIONS

ZONE	LTR	DESCRIPTION	DATE	APP'D

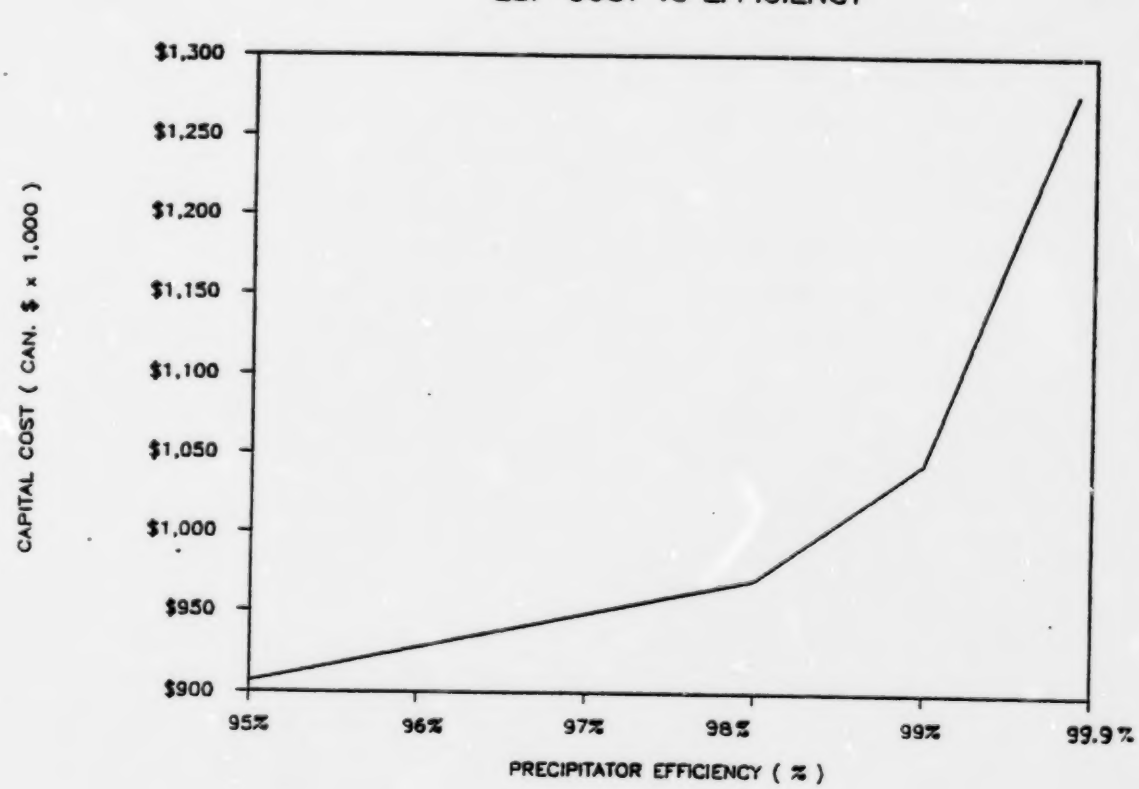

FIGURE 31

VonRoll — ENVIRONMENTAL ELEMENTS CORPORATION

OWMC TREATMENT FACILITY

PRECIPITATOR CAPITAL COST VS COLLECTION EFFICIENCY

LTR	DESCRIPTION	DATE

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DRAWING NO. A77

The optimization of particulate removal must take into consideration the characteristics of the Ring Jets™ located in the wet scrubber. The location of these in the wet scrubber is illustrated on Figure 32.

Ring Jet ™

After passing through the first and second stages of the scrubbing system, the gas stream is divided into multiple streams of approximately 2000 m^3 each and forced through the specially designed Ring Jets™, which comprise stage three. Several processes occur simultaneously in the annular gap formed by the Ring Jet™ venturis. The gas stream is accelerated to a high velocity and then scrubbing liquid is injected under pressure, perpendicular to the gas flow, into the annular gap formed in the Ring Jet™ venturi. This combination of high gas velocity and high liquid pressure, atomizes the liquid into very fine droplets. In addition, the high gas velocity creates a large velocity difference between the fine particles entrained in the gas and liquid droplets, which forces them to collide with each other. In this manner, the fine particles are "captured' in the liquid stream and removed from the gas stream.

The above description illustrates why the collection efficiency in the Ring Jets™ is a function of the energy input into stage three in the form of gas pressure drop (gas velocity) and liquid flow (liquid pressure). The gas pressure drop can be held constant with a varying gas volume by adjusting the liquid flow rate to the Ring Jets™. Therefore, the collection efficiency also remains constant within an operating range of 70% to 115% of design conditions.

Figure 33 entitled "Ring Jet Efficiency", illustrates the relationship between energy input (gas pressure drop) and collection efficiency. The top curve is the collection efficiency for total particulates, while the bottom curve is for particles in the range of 0.4 to 2.25 microns which can be expected to contain heavy metals and other residual contaminants. It is evident from Figure 33 that as the Ring Jet™ pressure drop is decreased, the fine particulate removal efficiency decreases more rapidly than total particulate removal efficiency. Therefore, the minimum operating pressure drop is restricted to 250 mm water gauge (WG). The maximum pressure drop

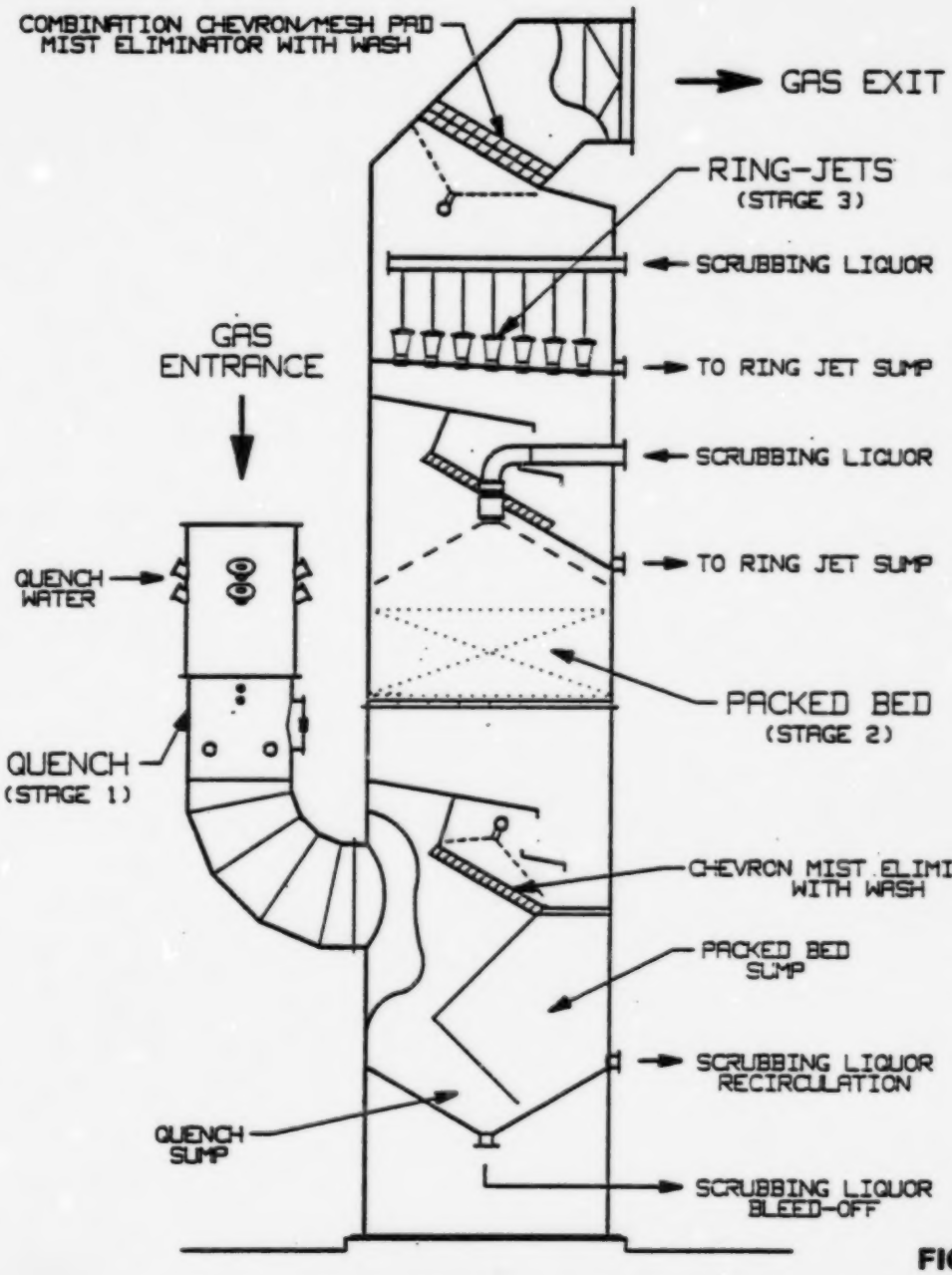

FIGURE 32

	ENVIRONMENTAL ELEMENTS CORPORATION
	OWMC TREATMENT FACILITY
	TYPICAL THREE-STAGE SCRUBBING SYSTEM
B	REDRAWN
A	REVISED PER CHANGE
	398012 A75 B

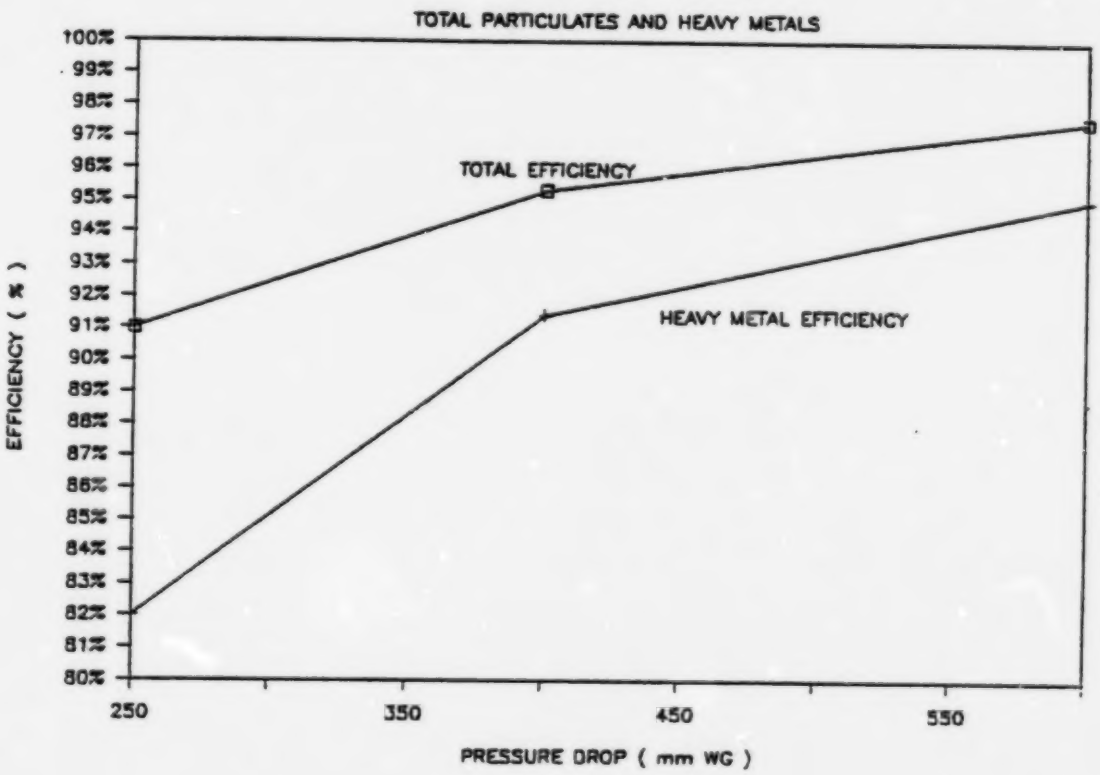

FIGURE 33

VonRoll	ENVIRONMENTAL ELEMENTS CORPORATION
OWMC TREATMENT FACILITY	
RING JET EFFICIENCY	
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DRAWING NO.: A80	

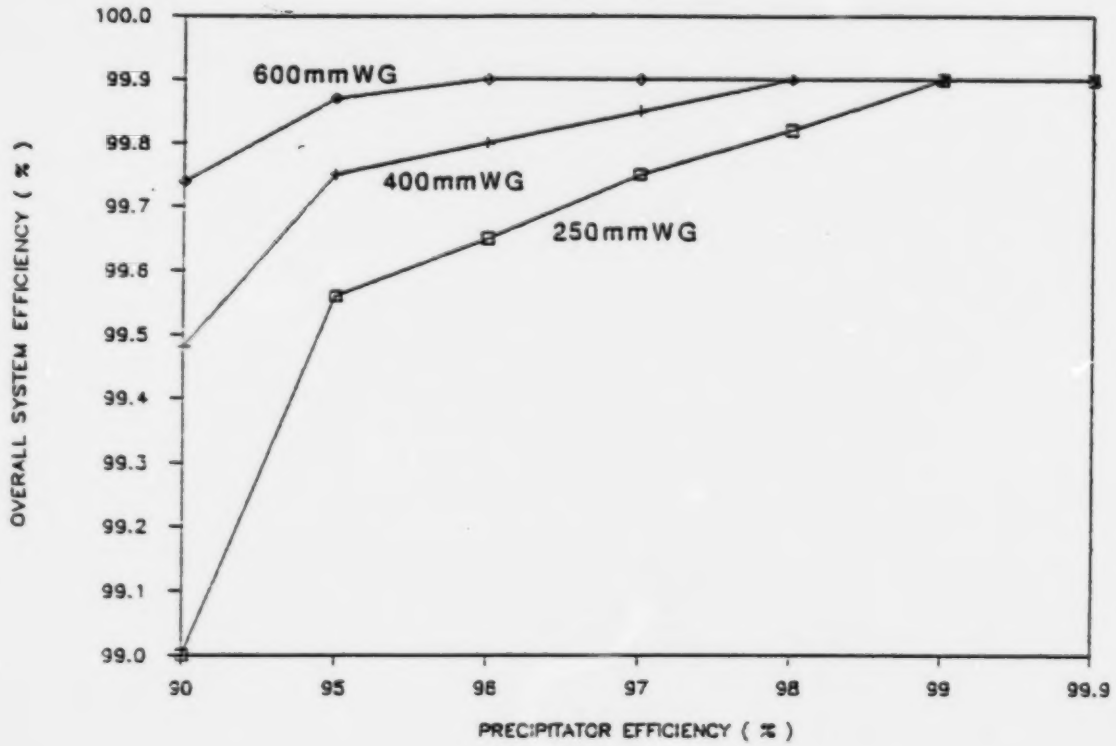
is limited to 600 mm WG due to the physical constraints of the equipment and the maximum efficiency for the Ring Jet™ stage therefore would correspond to the efficiencies obtainable at 600 mm WG.

The overall system collection efficiency for total particulates and aerosols (heavy metals) can be optimized by combining the removal efficiencies of the electrostatic precipitator and Ring Jets™. This is illustrated in Figures 34 and 35 entitled "System Particulate Removal Efficiency" and "Total System Heavy Metal Removal Efficiency" respectively.

The optimum combinations of electrostatic precipitator effiency and Ring Jet™ pressure drop can easily be determined by referring to Figure 34. As can be seen on this graph, the overall system has a maximum total particulate removal efficiency of 99.9%. This is illustrated by the fact that no combination of electrostatic precipitator efficiency and Ring Jet™ pressure drop results in a higher efficiency. Therefore, the optimization becomes a matter of determining the smallest precipitator and lowest Ring Jet™ pressure drop which will still result in an overall efficiency of 99.9%. It must be understood that increasing the size of the precipitator and/or the Ring Jet™ pressure drop beyond these points will not increase system efficiency, and to do so would not be cost effective.

The combination of electrostatic precipitator efficiency and Ring Jet™ pressure drop which provide a maximum system removal efficiency of 99.9% for total particulates are listed below:

Overall System Efficiency	Electrostatic Precipitator Efficiency	Minimum Ring Jet™ Pressure Drop
99.9%	96%	600 mm WG
99.9%	98%	400 mm WG
99.9%	99%	250 mm WG
99.9%	99.9%	250 mm WG



NOTE: OVERALL EFFICIENCY AS FUNCTION OF ESP EFFICIENCY AND RING JET PRESSURE DROP.

FIGURE 34

VonRoll ENVIRONMENTAL ELEMENTS CORPORATION

OWMC TREATMENT FACILITY

SYSTEM PARTICULATE REMOVAL EFFICIENCY

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DRAWING NO. A76

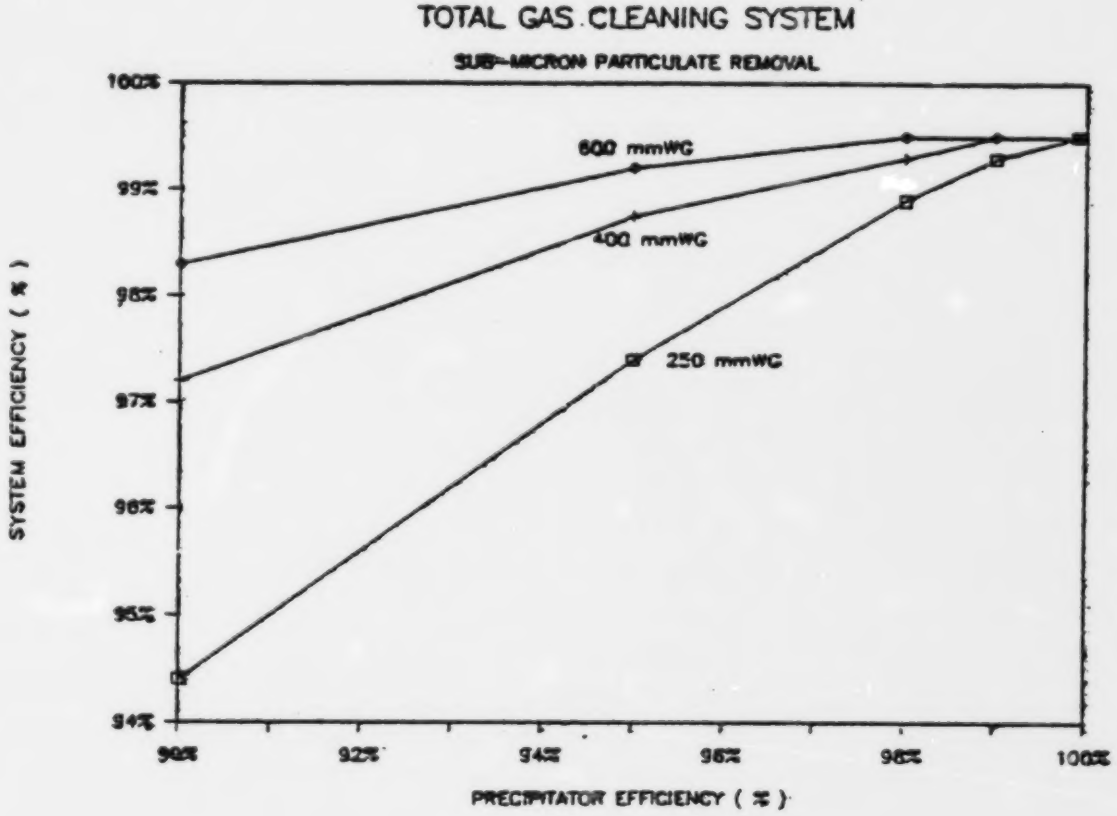

FIGURE 35

VonRoll	ENVIRONMENTAL ELEMENTS CORPORATION	
OWMC TREATMENT FACILITY		
TOTAL SYSTEM HEAVY METAL REMOVAL EFFICIENCY		
NONE	398012	A79 A

Figure 35 illustrates the same relationship between precipitator size and Ring Jet™ pressure drop for sub-micron aerosol (heavy metal) removal efficiency. In this case the maximum efficiency that can be obtained is approximately 99.5%.

The combinations of electrostatic precipitator efficiency and Ring Jet™ pressure drop which can provide a maximum system removal efficiency of 99.5% for fine particulates and aerosols, are listed below:

System Aerosol Efficiency	Overall Electrostatic Precipitator Efficiency	Minimum Ring Jet ™ Pressure Drop
99.5%	98%	600 mm WG
99.5%	99%	400 mm WG
99.5%	99.9%	250 mm WG

It is evident from this data, that optimum design should be based on the requirements for removal of aerosols. However, the optimum performance can be obtained for any three combinations of precipitator efficiency and Ring Jet™ pressure drop.

An economic comparison was conducted to determine the most cost effective combination of electrostatic precipitator size and Ring Jet™ pressure drop, which have a significant effect on capital cost and operating cost respectively. Details of this comparison are presented in Appendix D from which it will be seen that the optimum combination from a cost viewpoint is an electrostatic precipitator efficiency of 99% and a Ring Jet™ pressure drop of 400 mm WG.

This combination therefore was selected as a result of this optimization study.

Three-Stage Scrubbing System

The first stage is designed to quench the flue gas stream from 160°C to its saturated temperature of approximately 60°C. In addition to saturating the gas stream in a quench system, hydrogen chloride (HCl) and hydrogen fluoride (HF) absorption takes place. Since the purpose of the quench is to saturate the flue gas, there is nothing that can be done to optimize its performance.

A chevron mist eliminator is located between the quench and the second stage, and this has the effect of separating the liquid from the flue gas between the two stages. The result is a lower concentration of HCl and HF in the scrubbing solution in the packed bed of the second stage, which improves the absorption efficiency.

The second stage consists of a packed bed, which provides a large surface area for contact between the flue gas and the scrubbing liquid. As the flue gas rises vertically through the bed, counter-current to the liquid, HCl and HF are absorbed by the scrubbing liquid.

In general, the absorption rate, and therefore removal efficiency, is increased by increasing the surface area for contact between the flue gas and liquid or lowering the concentration of the contaminants in the liquid (which means high effluent quantities). However, increasing the size of the packed bed beyond a certain point will not increase efficiency. This is because the normal design procedure for sizing the bed and liquid rate is based on establishing equilibrium in the smallest bed possible. This point of equilibrium between the HCl and HF in the liquid and in the flue gas stream is determined by the vapour pressure of HCl and HF in the liquid at the operating concentration, temperature and pressure. The only one of these variables which can be controlled is liquor concentration and that is why the liquid loops in the first two stages are separated.

Therefore, the only remaining way to optimize the performance of the second scrubber stage is to select a packing which exhibits the following properties:

- o Maximum surface area per cubic meter of packing volume,
- o Low pressure drop,
- o Good liquid distribution,
- o Good gas distribution, and
- o Resistance to plugging.

A suitable packing having these desirable characteristics will be selected during the detail design phase.

Following the packed bed, flue gases pass through a "chevron" type mist eliminator and enter the third and final scrubbing stage for sulphur dioxide (SO_2) and aerosol removal. This is accomplished by the Ciba-Geigy Ring Jet^{TM} venturi section, originally developed for this purpose. Fine particle removal has been previously discussed on page 175.

The fine droplets generated in the Ring Jet^{TM} section provides the large surface area required for efficient absorption of SO_2. However, since SO_2 is not soluble in acid solutions and has a high vapor pressure, caustic soda (NaOH) must be added to the scrubbing liquid to react with the SO_2 as soon as it is absorbed. This allows the SO_2 to be absorbed in the liquid and prevents the dissolved SO_2 from being emitted back into the gas stream due to the vapor pressure. This approach permits high removal efficiencies to be obtained.

Sulphur dioxide absorption with a caustic soda solution is a topic that has been widely studied. The net result of these studies is the determination that SO_2 removal is a function of the following variables:

- o Ring Jet^{TM} pressure drop.
- o Scrubbing liquid-to-gas-ratio.
- o Scrubbing liquid pH.
- o Scrubbing liquid dissolved solids.

The first two variables have minimum values, above which no improvement in efficiency can be obtained and since the Ring Jet^{TM} section

is also designed to remove fine particles (aerosols), these minimum values will be exceeded.

This leaves the last two variables as the only items which can be optimized. They must stay within a specified design range for the system to work properly. As long as they stay within the design ranges identified below, no further optimization can be accomplished to further minimize sulphur dioxide emission to the environment.

pH:	6 to 7
Dissolved Solids:	0 to 6%

Mist Eliminators

Two alternative types of mist eliminators that can be used for final mist removal are "chevron type" and "mesh pad". The advantages and disadvantages of each are presented below.

o Chevron

Advantages

- Open design less prone to plugging.
- Low pressure drop.
- Can handle liquids with high solids content.
- Can be made of plastics for excellent corrosion resistance.
- Can handle high liquid loads.

Disadvantages

- High droplet removal efficiency only on large droplets:
  Vertical gas flow: 99% at 40 microns
  Horizontal gas flow: 99% at 20-25 microns
- Hard to clean when plugged.

o Mesh Pads

Advantages

- High efficiency: 99.9% at 12 microns
  99% at 5 microns
- Can be made of plastics for excellent corrosion resistance.
- Low pressure drop.

Disadvantages

- Can only handle moderate liquid loads.
- Will collect particles as well as droplets with high efficiency, which means it is more susceptible to plugging.
- Can not handle liquids with high suspended solids content.

It is evident from the above why chevrons have been the preferred option in past applications due to concerns regarding high solids content in the scrubber water. However the use of a high efficiency electrostatic precipitator will remove considerably more particulates than on previous installations thereby reducing the particulate load to the Ring Jet™ section and providing an opportunity for the use of mesh pads.

This is a highly desirable option since the addition of a mesh pad could reduce the re-entrainment of solids by as much as 50 percent compared with the use of chevron types. Therefore, the stack emissions could be significantly reduced, because entrained solids normally represents approximately 25 to 50% of the total emissions on scrubbers of this type. The cost for the addition of a mesh pad should be quite modest.

The optimized design proposed for OWMC's Facility will therefore include a combination chevron/mesh pad at the outlet of the wet scrubber. The chevron will act as a coarse mist eliminator and reduce the loading and the potential for plugging in the mesh pad, located downstream of the chevron.

Summary

The optimized design for the flue gas treatment system is as follows:

- o Spray dryer having a rotary atomizer.

- o Three field electrostatic precipitator having an efficiency of 99%, and equipped with rigid electrode or rigid frame discharge electrodes.

- o Three stage wet scrubber
  - First stage quench followed by chevron mist eliminators.
  - Second stage packed bed followed by chevron mist eliminators.
  - Third stage Ring Jets™ operated at 400 mm WG pressure drop.
  - Final mist eliminator to be a combination chevron/mesh pad.

This optimized design will reduce the discharge of residual contaminants to the environment to the lowest achievable levels.

The expected typical and maximum residual emissions from the incineration plant stack, following the adoption of this optimized design, are presented in Section 4.5 (pg. 212) dealing with performance.

4.3.5 FLUE GAS REHEATING

It is not uncommon for flue gas treatment systems involving wet scrubbers to incorporate a means of reheating treated flue gases prior to them being discharged to the environment via a stack.

Typical facilities which include flue gas reheating are:

- o GSB, Ebenhausen, Bavaria, West Germany, and
- o Bayer AG, Leverkusen, West Germany.

Other facilities which do not reheat their flue gases are:

- o HIM, Biebesheim, West Germany, and
- o BASF, Ludwigshafen, West Germany.

The main benefits of reheating flue gases are as follows:

- o a slight reduction in the visible steam plume from the stack, during warm weather operation,
- o improved buoyancy of the plume, which is of particular benefit during adverse atmospheric conditions,
- o reduced concerns regarding corrosion in flues, and
- o easier monitoring of the "dry" flue gases.

From an operational perspective there is no significant advantage to justify the additional costs involved in reheating the flue gas prior to discharge.

However, plume dispersion modelling by the Ontario Research Foundation has shown that the ground level contaminant concentrations at point of impingement can be reduced by 10 - 13% for an incineration plant with one unit, and by 21 - 27% for a plant with two units operating, by incorporating flue gas reheating. These data are based on OWMC's proposed Facility having a stack height of 60 m and with flue gas being reheated to 130°C. The additional plume buoyancy was shown to be particularly beneficial under adverse atmospheric conditions.

While the stack emissions from OWMC's Facility are well below the permitted values in Ontario, this was not considered a valid reason to ignore the benefits available through reheating of flue gases, since OWMC is not designing the Facility to merely comply with Ontario's Regulations. It was therefore considered that the benefits of flue gas reheating are worthwhile and that the risk to human health and impact on the environment can be further reduced by including flue gas reheating in the incineration plant design. These factors were considered more important than the modest increase in capital and operating costs involved.

Reheating of flue gases to 130°C therefore, has been included in the design for OWMC's proposed Facility.

4.3.6 STACK

A stack height of 60 m was selected following stack modelling studies by Ontario Research Foundation to determine the relative effects of various stack heights.

It was determined that while a higher stack could be used to lower the contaminant concentrations at ground level, for example a 100 m high stack would reduce ground level concentrations at point of impingement by approximately half, higher stacks also represent a higher aesthetic intrusion into the environment.

On the other hand, a lower stack would result in potential interference of the stack plume by air currents created by wind movement around building structures.

Stack modelling studies conducted to date by Ontario Research Foundation indicate that the residual emissions from OWMC's incineration plant will be a small percentage of those permitted by Ontario's Regulations. OWMC therefore chose the 60 m high stack in the knowledge of this information and having regard to concerns which have been expressed against the use of a tall stack.

The 60 m high stack is a little over twice the adjacent building height, in accordance with good practice.

The stack height could be increased, however, if the risk based conclusion of future studies on potential upset and malfunction scenarios indicate it would be beneficial to do so.

4.3.7 RESIDUE HANDLING

Two distinctly different residues have to be disposed of from the incineration plant.

Liquid slag from the rotary kiln is solidified by quenching in a water tank and discharged into a container. This material is dense and lumpy, and can be transferred to the engineered landfill in standard containers without risk of dusting or concerns regarding human exposure.

The second residue is quite different. Boiler ash and salt from the flue gas treatment system is dry, fryable and prone to dusting. This material can be expected to contain heavy metals and other residual contaminants, which are a concern to human health if inhaled.

Transfer of this material to the solidification plant for treatment would provide opportunities for dusting not only at the incineration plant where the residue would be loaded into containers, but also at the solidification plant where it would have to be unloaded and transferred to the solidification plant mixers.

Mixers have been provided at the incineration plant in order to mitigate this potential health concern. In this manner, boiler ash and salt will be deposited in the mixers directly via sealed ash conveyors, thereby minimizing risk to human health and impact on the environment that might otherwise result due to the release of these materials to the environment.

The solidified material will be transferred to the landfill as a damp clay like material, and will not be prone to dusting.

4.3.8 REAGENTS

The main reagents used on the incineration plant are employed in the flue gas treatment system. Caustic soda (NaOH) is used in the wet scrubber in preference to calcium based reagents, since the latter are prone to scaling and solids deposition due to the formation of gypsum in the scrubber water circuits. This is more fully discussed in Section 3.5.1 (pg. 33).

Hydrated lime ($Ca(OH)_2$) is used in preference to caustic soda for neutralization of scrubber effluent, since it is substantially lower in cost and scaling/deposition is less of a concern. Hydrated lime is also

preferred to quicklime (CaO) and limestone ($CaCO_3$) since the potential operating cost reductions, which are evident in large reagent consuming processes, do not exist on this relatively small reagent application and the additional system complexity cannot be justified. This is further addressed in the Process Area Report, Physical/Chemical Treatment (Ref: Monenco Limited[6]), where a similar approach is proposed for the physical/chemical treatment plant.

Relatively small quantities of morpholine, sodium sulphite and trisodium phosphate will be used in the auxiliary equipment area of the incineration plant for boiler water pH adjustment, scavenging oxygen from feedwater and water conditioning purposes. These chemicals are routinely used in this application throughout Ontario and no human health or occupational risks are anticipated providing the materials are handled and used in accordance with recommended practices.

4.3.9 AUXILIARY SYSTEMS

A simplified representation of the steam system is shown on Figure 36, and of the boiler feedwater and condensate system on Figure 37.

Steam System

The preliminary design of the steam system is based on the following main considerations:

- Justification of heat recovery for the incineration process was determined by studies presented in Chapter 3.

- Two auxiliary boilers are provided so that essential Facility steam demands, such as heating services, can be maintained when the incineration plant is out of service and only one of the two auxiliary boilers operating. i.e. This covers a double contingency failure condition.

- The preliminary sizing of the auxiliary boilers is 30 t/h each, based on the results of preliminary plantwide steam system modelling.

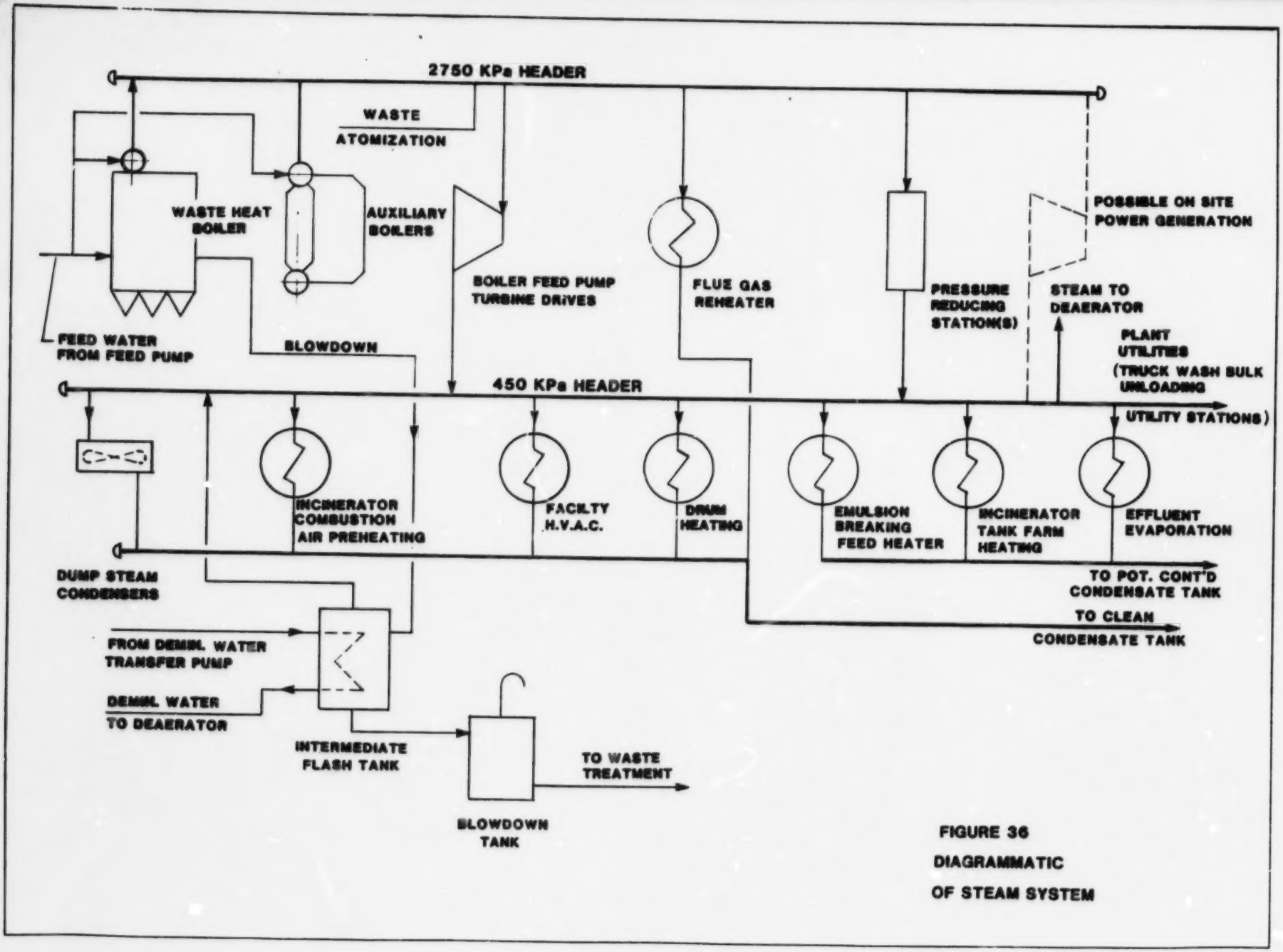

FIGURE 36
DIAGRAMMATIC
OF STEAM SYSTEM

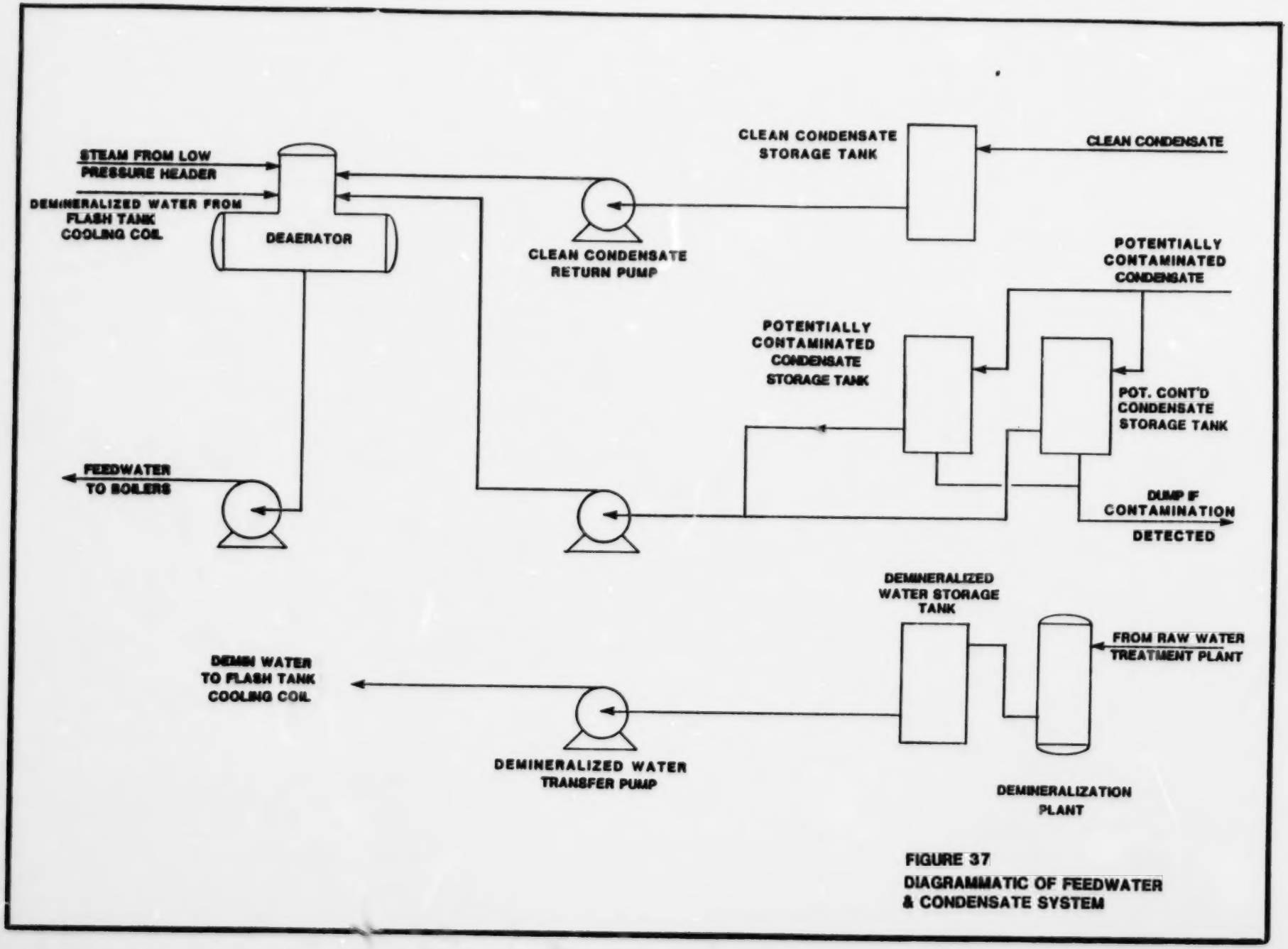
STEAM FROM LOW PRESSURE HEADER
DEMINERALIZED WATER FROM FLASH TANK COOLING COIL
DEAERATOR
CLEAN CONDENSATE STORAGE TANK
CLEAN CONDENSATE
CLEAN CONDENSATE RETURN PUMP
POTENTIALLY CONTAMINATED CONDENSATE
POTENTIALLY CONTAMINATED CONDENSATE STORAGE TANK
POT. CONT'D CONDENSATE STORAGE TANK
FEEDWATER TO BOILERS
DUMP IF CONTAMINATION DETECTED
DEMINERALIZED WATER STORAGE TANK
FROM RAW WATER TREATMENT PLANT
DEMIN WATER TO FLASH TANK COOLING COIL
DEMINERALIZED WATER TRANSFER PUMP
DEMINERALIZATION PLANT

FIGURE 37
DIAGRAMMATIC OF FEEDWATER & CONDENSATE SYSTEM

- A dual steam header system is presently envisaged, one at 2750 kPa pressure and one at 450 kPa pressure.

- Steam turbine drivers for essential drives such as boiler feed pumps, will be connected to the 2750 kPa header.

- The dual steam header provides greater reliability of steam supply to services connected to the lower steam header, during upsets or periods of instability. Essential heating services are for this reason connected to the 450 kPa header.

- The medium pressure header steam conditions have been tentatively selected at 2750 kPa/300°C to provide the highest conditions proven in similar installations elsewhere, in recognition of potential corrosion problems in the waste heat recovery boiler (Section 4.3.3, pg. 151) and the desire to maintain an option for efficient on-site power generation.

- The low pressure header has been selected at 450 kPa based on experience with similar industrial steam systems. The steam is nominally dry saturated but has a small amount of superheat (10°C) to minimize condensation in the distribution system.

- Air cooled steam condensers will condense any excess steam available at the 450 kPa header.

- The 2750 kPa header will be controlled by a combination of system pressure reducing valves and auxiliary boiler firing rate. The 450 kPa header will be controlled by a combination of pressure reducing valves and dump air condenser load.

- The steam pressures will be reviewed and finalized during detailed engineering.

Boiler Feedwater System

The preliminary design of the boiler feedwater system is based on the following factors:

- o The system has two primary components:
  - boiler make-up feedwater treatment plant, and
  - deaerator and related feed pump system.

- o The boiler make-up feedwater treatment plant will produce demineralized water from the Facility raw water supply, for use as makeup to the boilers. Two identical systems of 8 t/h capacity will be provided.

- o The deaerator will be sized to receive clean and potentially contaminated condensate returns and make-up water from the treated water storage tanks. The deaerator storage tank will have sufficient capacity to provide 10 minutes supply of boiler feedwater at maximum plant steam demand.

- o One electric and two steam driven boiler feed pumps will be provided, each rated for 50% of maximum feedwater demand. One steam driven pump will always be operating, except during initial start-up.

- o The feed pumps will supply deaerated water, heated to a temperature of 150°C, to the various boilers and desuperheating stations.

Condensate System

- o Two condensate collection systems will be provided, namely:
  - clean condensate system, and
  - potentially contaminated condensate system.

- o The clean condensate system will receive clean condensate from the dump air cooled condenser, building heating system, plume suppression heat exchanger and combustion air heating system.

Condensate will be collected in a clean condensate receiving tank and returned to the deaerator via transfer pumps.

- o The potentially contaminated condensate system will receive condensate which could potentially have been contaminated by leakage of heat exchangers in its respective service. Condensate from building heating system exchangers could qualify as "potentially contaminated" rather than clean where it emanates from steam-glycol heat exchangers.

- o Potentially contaminated condensate will be received into one of two storage tanks which can be isolated in the event that serious contamination is detected. Continuous condensate quality monitors will be located in individual condensate lines from major condensate sources.

- o Contaminated condensate will be discharged to the physical/ chemical treatment plant.

The steam, boiler feedwater and condensate systems will be designed in the manner proposed to reflect the high degree of reliability that has been established as a requirement for all auxiliary/utility systems on OWMC's Facility.

4.3.10 INCINERATION PLANT LAYOUT

The arrangement of the incineration plant has previously been presented on Figures 12 and 13 (pages 108, 109). Pertinent features of the arrangement are as follows:

- o The following areas are located inside buildings:

  - Waste pits and waste feeding systems.
  - Combustion system including rotary kiln and secondary combustion chamber.
  - Flue gas cooling system including waste heat recovery boiler.

- Auxiliary equipment including auxiliary boilers, feedwater, condensate and steam systems.
- Control room and electrical room.
- Auxiliary equipment associated with wet scrubber including scrubber circulating pumps, reagent systems.
- Induced draft fan.
- Boiler ash and salt solidification mixers.

o While in the majority of cases the reason for indoor location of equipment is to accommodate improved operator surveillance and maintenance of equipment during winter conditions, the following additional points should be noted:

- Enclosure of waste pits is provided to preclude precipitation from contacting the dry solid waste and also to minimize release of contaminants to the environment during unloading, storage and handling of the waste.

- Enclosure of the kiln would permit the containment of any releases from the kiln seals (during temporary pressurization of the incinerator) and controlled ventilation of the area as well as restricting personnel access. While Figures 12 and 13 illustrate a completely enclosed kiln, the degree of enclosure will be determined during the detailed engineering phase.

- Enclosure of the induced draft fan is to mitigate high noise levels anticipated from this equipment.

- Enclosure of water systems in the auxiliary equipment annex and scrubber auxiliary building provides additional reliability during cold weather operation, including improved safeguards against freezing of lines during winter shutdown.

- o The following areas are located outdoors:
  - Flue gas treatment system including spray dryer, electrostatic precipitator and wet scrubber tower.
  - Slag discharge into containers.
  - Residue conveyors associated with flue gas treatment system (partly enclosed).
- o Equipment located outdoors does not require close operator surveillance and it is accepted industry practice in Canada to locate similar systems outdoors.
- o Provision is made (i.e. space reserved) for the installation of a second incineration process system, if so required in the future.

4.4 PLANT OPERATION

The following sections outline the incineration plant operating philosophies and safety features which ensure that the plant performs as expected and is capable of operating in a safe, environmentally sound manner during both normal operation and plant upset conditions.

4.4.1 OPERATING PROCEDURES

Figure 38 provides a schematic overview of the operating philosophy of the incineration plant. The key operating features of the incineration plant are summarized below:

- o The incineration plant will operate continuously, 24 hours per day, 7 days a week.
- o The plant is expected to operate 7000 hours per year with the remaining time being available for planned and unplanned outages

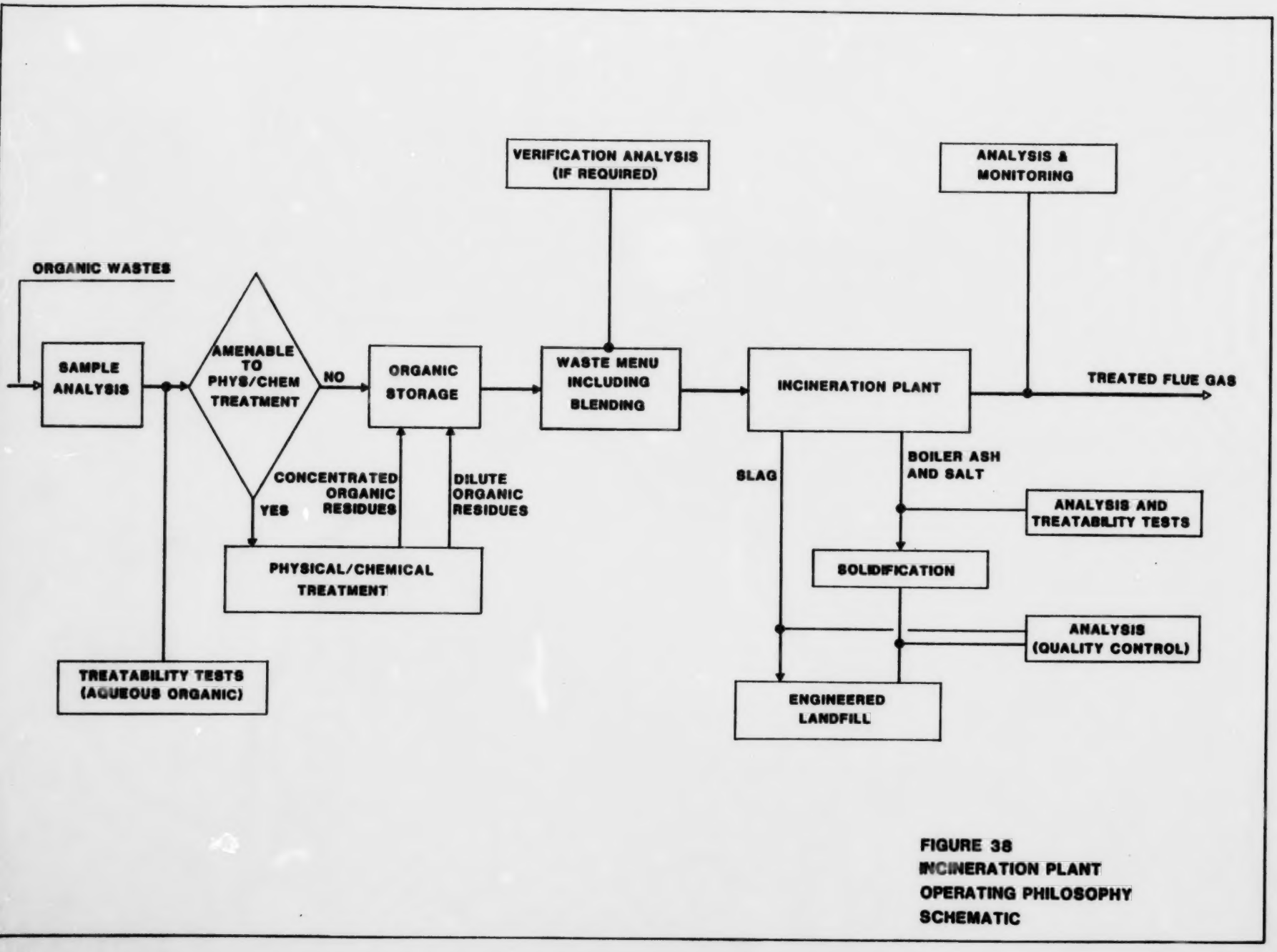

FIGURE 38
INCINERATION PLANT
OPERATING PHILOSOPHY
SCHEMATIC

for maintenance. At least one major planned shutdown for maintenance and repairs to refractory structures will be scheduled annually.

- o Aqueous organic waste will, wherever possible, be treated by physical/chemical methods to remove water, with the concentrated organic residue being returned to the incinerator (organic) tank farm for storage, in readiness for incineration.

- o Other residues from the physical/chemical treatment plant which are unsuitable for solidification due to their organic content, will be incinerated. These may still have relatively low organic content and are shown on Figure 38 as dilute organic residues.

- o Daily menus will be prepared for the incineration plant, identifying the types of wastes to be incinerated, feed rates, sequences, and required blending. It should be noted that:

  - Some waste types such as aqueous organics and contaminated water may be pumped directly from the storage tank to the incinerator.

  - Segregated organic wastes such as PCBs will preferably be transferred directly from the storage tank to the incinerator.

  - Sludges will be blended in the blending tanks located in the incinerator tank farm.

  - The remaining organic liquids such as waste oils and solvents, which are used for combustion control purposes, will be mixed in blending tanks located in the incinerator tank farm.

  - The sequence and feed rate of drums will be pre-determined as part of the daily menu.

  - The type, sequence and charge rate for bulk solids from the waste pits will be pre-determined as part of the daily menu.

- o Additional analyses may be obtained of blended wastes in order to verify that important parameters such as heating value, chlorine and sulphur content are within prescribed limits. This will be a verification check analysis, since storage tank contents will have been previously characterized from analyses conducted on samples prior to delivery and verified by "fingerprint" analysis at the time of delivery.

- o Documentation will be provided to operators giving instructions on special procedures which must be observed during the handling and treatment of wastes including special emergency response procedures which must be followed in the event of spillage.

- o The measures described in the previous three paragraphs will enable rigid control to be maintained over the nature of waste fed to the incinerator.

- o Treated flue gases discharged from the incineration plant will be continuously monitored for contaminants indicated in Section 4.2.10 pg. 119. In addition, periodic stack sampling will be conducted for selected contaminants which cannot be continuously monitored eg. heavy metals.

- o Samples of boiler ash and salt (residue) from the incineration plant will be taken periodically for analysis and solidification treatability tests to ensure that the optimum formulation is being used. The relative consistency of this residue stream will permit batches of these materials to be solidified as they are received from the incineration process without waiting for the results of specific treatability tests on each sample. This would in any case be impractical due to the time required.

- o Samples of slag will be taken for analysis for record purposes.

It is believed that the operational approach described above will provide a high level of confidence that wastes are being properly treated

and the results of analytical tests on residues and treated flue gases will verify that this is the case. In this manner, OWMC will be in a position to demonstrate that wastes are being treated in a manner which minimizes risk to human health, and impact on the environment.

4.4.2 OPERATIONAL SAFETY FEATURES

PROCESS SAFETY FEATURES

This section identifies some of the main safety features that are incorporated in the design to ensure that both human and environmental safety is achieved at all times.

Waste Feed Cut-Off

Complete or partial waste feed to the incineration system will be cut off automatically should any of the following events occur:

- High carbon monoxide or high total hydrocarbon content in the treated flue gas.
- Low temperature in the secondary combustion chamber.
- Low primary and/or secondary air flow.
- Sustained abnormal pressure in secondary combustion chamber.
- High steam pressure in the boiler drum.
- Failure of two precipitator fields.
- High temperature in the secondary combustion chamber.
- Low water level in waste heat recovery boiler.
- Malfunction of the induced draft fan.
- Failure of two out of three thermocouples located after secondary air injection in the secondary combustion chamber.
- Interruption of quench or scrubber water circulation.
- Power failure.

Many of these events are further addressed in the following paragraphs.

Waste Feed Interruption

An unexpected interruption of waste feed will be detected by a loss of temperature in the secondary combustion chamber, unexpected operation of the auxiliary fuel burner in the sidewall of the secondary combustion chamber and a significant increase in the oxygen concentration level in the flue gas. In this situation, there is no risk of imminent harm to human health or the environment and no special or unusual action is required. The burners in the front wall of the kiln and in the secondary combustion chamber will be utilized, as required, to maintain required temperatures while the situation is rectified.

Loss of Auxiliary Fuel (Natural Gas)

An interruption in the natural gas supply to the burners in the front wall of the kiln and in the secondary combustion chamber will be detected by a loss of pressure in the fuel line. Should this situation occur during start-up or shutdown procedures, there will be no risk of imminent harm to human health or the environment and no special or unusual action will be required since in the first instance waste will not have been introduced to the system while in the second instance the destruction of waste should have been completed. Should this situation occur during normal operation of the incineration system when operation of the burners is required to maintain temperature in the secondary combustion chamber, then all waste feed will be suspended until normal operating conditions can again be established and maintained.

Combustion Temperature Limits

Temperatures in the combustion system will be measured by temperature sensors located in the secondary combustion chamber. Organic waste cannot be introduced to the incinerator unless the flue gas temperature before secondary air addition is above 1050°C, aqueous waste cannot be introduced unless the temperature is above 1100°C, and segregated organic wastes such as PCB's cannot be introduced unless the gas temperature prior to secondary air addition is above 1250°C. Control interlocks will prevent waste being introduced unless these temperature conditions are satisfied.

Conversely, the feeding of segregated organic wastes will be automatically shut off should the flue gas temperature prior to secondary air addition fall below 1200°, aqueous waste feed will be shut off should the flue gas temperature fall below 1050°C, and organic waste feed will be shut off if this temperature falls below 1000°C.

It should be noted that these are safety interlocks and the normal operating temperatures prior to and after secondary air addition will be approximately 1200°C and 950°C respectively. The operator will have ample warning and time for corrective measures should these temperatures start to fall, and thereby avoid the initiation of safety interlock features.

Nevertheless, should flue gas temperature before secondary air injection drop below 1050°C, all aqueous waste feed will be stopped automatically in an attempt to prevent a further decrease. Should the temperature continue to drop the auxiliary fuel burner in the secondary combustion chamber will start up automatically when the temperature reaches 1030°C. If this does not remedy the situation all waste feed will automatically be cut off when the temperature drops below 1000°C.

Segregated organic wastes such as PCBs can only be fed to the rotary kiln when the kiln front wall burner is operating, thereby providing additional assurance that high destruction efficiencies will be achieved and discharges to the environment minimized.

Abnormal Level of Excess Air in the Combustion System

The level of excess air in the combustion zone will be monitored by measuring the concentration of oxygen in the flue gas. Moderate fluctuations in the oxygen level are normal, however significant, sustained deviation from the established level indicates a malfunction.

Heat input by the organic liquid lance will be controlled by the oxygen level in the flue gas in normal operation. However, if the oxygen content drops below or rises above a predetermined acceptable operating

range then control of heat input by this lance is automtically switched to temperature control based on temperature in the secondary combustion chamber.

A drop in the concentration of oxygen in the flue gas indicates excessive waste feed (heat release) or a malfunction of the primary or secondary combustion air systems. In either case, a decline in the concentration of oxygen will result in an increase in the temperature in the secondary combustion chamber.

The control system will respond automatically to falling oxygen concentration or increasing temperature by first reducing the high heating value liquid waste feed rate. On a continued decline in oxygen concentration or a continued increase in temperature, or in the event of detection of a malfunction of either the primary or secondary combustion air systems, an alarm will sound followed by suspension of all waste feed to the system.

Conversely, an increase in the concentration of oxygen in the flue gas indicates inadequate waste feed (heat release) or an increase in the amount of combustion air. In either case, an increase in the concentration of oxygen will result in a decline in the temperature in the secondary combustion chamber.

The control system will respond automatically to increasing oxygen or decreasing temperature by first increasing the high heating value liquid waste feed rate. On a continued decrease in temperature, an alarm will sound followed by automatic ignition of one of the auxiliary fuel burners in the secondary combustion chamber. Further decline in temperature, or in the event of an excess amount of combustion air or if a burner flame-out condition is detected, will result in a second alarm being sounded followed by suspension of all waste feed to the system.

Abnormal Pressure in the Secondary Combustion Chamber

A sustained positive pressure in the secondary combustion chamber is indicative of excessive waste feed, malfunction of the induced draft fan or a blockage somewhere in the path of the flue gas as it flows through the system. In any case, waste feed is suspended if the positive pressure continues for more than a few seconds. A sustained excessively negative pressure is indicative of insufficient waste feed or of a malfunction of the primary air fan, secondary air fan or induced draft fan. Here too, waste feed would be suspended.

Malfunction of the Primary or Secondary Combustion Air Fans

A malfunction of the primary or secondary air fans will be detected by measuring air flow at the fan discharge. Loss of air flow from either the primary or secondary combustion air fans will result in immediate suspension of all waste feed and initiation of a controlled shutdown of the system. The burner in one of the secondary combustion chamber's sidewalls will be utilized, as required, to maintain temperatures in the combustion zone until destruction of the waste is complete.

Water Level in the Boiler Too Low

The water level in the waste heat recovery boiler will be monitored by observing the level of water in the steam drum. In normal operation the water level in the steam drum is controlled automatically by a three element feed water controller. Low water level is indicative of a malfunction of the boiler feed water system or a major leak in the boiler. In either case, immediate suspension of waste feed will occur and a controlled shutdown of the system is initiated.

Temperature in the Spray Dryer Too High

The flue gas temperature in the spray dryer will be monitored by temperature sensors located at the entrance and exit of the dryer. High entrance temperature is indicative of a malfunction of the flue gas cooling system or heavy fouling of the boiler, whereas high exit temperature from the spray dryer may indicate a malfunction in the spray dryer feed system. High temperature of the flue gas leaving the spray dryer will automatically initiate operation of the emergency water system and an alarm. If the

condition persists, all waste feed will be suspended and a controlled shutdown initiated by operations staff. Low entrance temperature may cause operational difficulties since the flue gas may not have sufficient heat to evaporate the required quantity of scrubber effluent. However, this condition can only occur during startup and shutdown of the Incineration Plant. Operations staff will be trained when and how to start introduction of neutralized scrubber blowdown or water to the spray dryer. Additionally, the operating manual will detail the necessary steps and conditions.

Loss of Power to the Electrostatic Precipitator

The electrostatic precipitator will have three electrical fields. Power to the fields will be monitored with voltmeters on the electrical feed, and a loss of power to two fields will result in an immediate suspension of waste feed and a controlled shutdown of the system.

Malfunction of the Induced Draft Fan

A malfunction of the induced draft fan will be detected by an increase of pressure in the secondary combustion chamber, an unexpected reduction in fan speed, or an unexpected loss of electrical power to the induced draft fan motor. A malfunction of the induced draft fan will result in immediate suspension of all waste feed. The primary and secondary combustion air fans will also be shut down.

It should be noted that the induced draft fan has an auxiliary motor drive which can continue to operate the fan during emergency shutdown, as further described under "power failure".

Interruption of Quench or Scrubber Water Circulation

A loss of quench or scrubber water circulation will be detected by a variety of indicators including loss of water pressure, loss of scrubber liquor flow, loss of electrical power to one or more of the circulation pumps as detected by auxiliary contacts on the pump motor starters, high temperature of the flue gas leaving the quench section or loss of fluid level in the scrubber liquor sumps. All quench and scrubber circulation pumps will be spared and failure of the operating pump will initiate the

automatic starting of its spare except in the instance of a general power failure which will cause all waste feed to be stopped and a system shutdown initiated. High temperature of the flue gas leaving the quench section will automatically initiate operation of the emergency water system and an alarm.

Power Failure

The potential for emission of contaminants to the environment during a power failure will be mitigated by the following design features and operational sequences.

- Plant control and status monitoring systems are connected to an uninterruptible power supply (battery system) so that such systems remain in operation throughout a power failure event.

- When burning non-liquid waste contaminated with PCBs, the secondary combustion chamber burner used to maintain temperature in the secondary combustion chamber will be placed in operation. The normal power supply to those items necessary to keep the burner in operation will be supplemented by an alternate supply arranged to ensure that the burner will remain operational during a power failure. The burner will automatically modulate to the high fire position, upon power failure, thereby providing additional assurance that organics volatilized in the rotary kiln, will continue to be destroyed.

- Waste feed to the incineration system is automatically terminated upon power failure.

- The emergency electrical power system will be initiated and electrical power will be provided to critical items of equipment within thirty seconds (Ref: Monenco Limited[9]).

- During the intervening period:

  - the induced draft fan will gradually slow down but continue to draw flue gas through the system, preventing the egress of gases through kiln seals, feed chute, boiler seals and other potential sources at the working level,
  - temperatures in the combustion system begin to fall, but remain at values which will destroy residual organic contaminants in the system,
  - visible combustion (flame) in the kiln is substantially reduced, although the residual heat, together with air drawn into the system by the induced draft fan, will be sufficient to complete combustion of any material in the kiln, over an extended period,
  - the waste heat recovery boiler continues to cool flue gases, and thereby generate steam, and boiler feedwater supply is not interrupted since the steam turbine driven feed pumps continue to operate,
  - the flue gas temperature from the boiler drops immediately due to the reduced flue gas flow,
  - flue gases passing through the spray dryer and electrostatic precipitator at higher than normal temperatures will not cause any harm, since both units will be structurally designed to withstand temperatures of up to 425°C,
  - quench water continues to be provided to the first stage of the wet scrubber from head tanks, located in the stack, which are sized to provide up to 15 minutes of water supply,
  - flue gases continue to be partially treated in the wet scrubber by the removal of acid gases and particulates in the quench section and also the residual water in the packed tower, albeit at a reduced efficiency, and
  - flue gases continue to be discharged to atmosphere via the stack at reduced volumes.

- When the emergency power system is operational, within thirty seconds of power failure, the following equipment will be restarted automatically:

- Induced draft fan auxiliary drive will be started to continue operation of the fan, at reduced speed, to maintain the flow of residual flue gases and prevent egress of gases to atmosphere in the operating areas.
- Wet scrubber circulating water pumps will restart, thereby reinstating the scrubber at full operational efficiency.
- Rotary kiln drive motor.
- Equipment cooling systems.
- Electrically driven boiler feed pump and associated feedwater transfer and condensate pumps.
- Required auxiliary systems.

o The incinerator can continue to be shutdown under controlled conditions or it can be restarted in an orderly manner once normal power has been restored to the plant.

VENTILATION

The following features are included to mitigate risk to human health and discharges to the environment:

o Waste storage tanks and blending tanks are connected to an inert (nitrogen) blanket system and vents from this system are discharged to the incinerator or to atmosphere via a scrubbing system when the incinerator is not operating (Ref: Monenco Limited[9]).

o The waste storage pit area will be ventilated to the incinerator by the primary air fan or to atmosphere using roof mounted ventilation fans when the incinerator is not operating.

o The kiln-front area including drum conveyor area will be well ventilated to prevent the buildup of harmful or dangerous concentrations of organics. Drums will be covered either with a loosely placed top or a plastic cover.

o The control room will be ventilated and air conditioned.

- The rotary kiln including end seals will be located in an isolated room with controlled access for personnel protection. The room will be vented to atmosphere via roof vents.

- The incinerator building enclosing the secondary combustion chamber, waste heat recovery boiler and auxiliary equipment will be ventilated in accordance with normal industry practice. No special contaminant control measures are required in this area.

- All other buildings are ventilated in accordance with normal industry practice, there being no special contaminant control requirements.

FIRE

A comprehensive fire prevention, detection and control system will be installed at the Facility and designated staff will be trained in fire fighting methods (Ref: Monenco Limited[9]).

Specific features of this system in the incineration plant are as follows:

- Firewater standpipes and hose cabinets will be located in the incinerator and auxiliary equipment areas.

- The control room will be protected by a Halon extinguishing system.

- Local deluge water systems will be provided in the waste pit area.

- A foam fire protection system will be provided over the incinerator bulk waste feed chute.

- A foam deluge water spray fire protection system will be provided over the drum conveyor from the drum handling building to the incinerator feed chute.

SPILLS AND LEAKS

- Accidental spills of organic wastes or other process fluids (eg. scrubber water) will be contained by provision of curbing and sumps. Spills will be isolated and cleaned up using predetermined safety procedures.

- Ash or salt spills will similarly be isolated, cleaned up and the material disposed of on-site. Particular attention will be given to good housekeeping in the residue handling areas.

EMERGENCY PROVISIONS

- Escape routes will be provided from all areas of the incineration plant for use in the event of a fire. At least two alternative escape routes will be provided from elevated floors inside buildings.

- Emergency eyewash and shower stations will be provided at strategic locations in the incineration plant, notably where reagents/ chemicals are being prepared and handled.

- An Emergency Response Plan will be established prior to Facility startup that will, among other things, identify the actions to be taken and the personnel, equipment, training, etc. needed to deal with any emergency situation that can be anticipated.

4.5 PERFORMANCE

This section addresses the performance of the optimized rotary kiln incineration system in terms of residual contaminant emissions discharged to atmosphere. The capability of the incineration system in the destruction of organic wastes and in the removal of contaminants from the raw flue gases, is demonstrated in the following pages.

The characteristics of solid residues discharged from the incineration process are also addressed.

4.5.1 FLUE GAS EMISSIONS

It is important to emphasize that over 99.98% of the flue gases discharged from OWMC's incineration plant stack will normally consist of nitrogen and oxygen from the combustion air, carbon dioxide formed during the combustion process and water vapour either produced in the combustion process or absorbed during flue gas treatment. None of these constituents are generally considered harmful to health or to the environment. While this statement is in itself an indicator of how well OWMC's Facility treats organic wastes, it is the remaining small percentage of the flue gas which remains a concern and which therefore must be examined in detail.

Table 4 presents the quality of treated flue gas expected from OWMC's incineration plant. The maximum emissions are expressed on the same basis as German Regulations and as such the maximum half hour average concentrations may exceed stated values by up to 100% for one half hour period during each day. It should be emphasized that the performance optimization presented earlier in Chapter 4 and the flue gas quality predicted in Table 4 are supported by operating data on a similar operating facility (Ref: Maurer[42]).

Destruction of Organics

The destruction of organics warrants more detailed examination, since these are of particular concern to human health.

TABLE 4
EXPECTED FLUE GAS EMISSIONS

		Expected Maximum Emissions mg/Nm^3 (1)(2)	Expected Typical Emissions mg/Nm^3 (1)(3)
Particulates		35	15
Hydrogen Chloride	(HCl)	35	15
Sulphur Dioxide	(SO_2)	175	150
Hydrogen Fluoride	(HF)	2	1
Nitrogen Oxides	(NO_x)	--	200
Carbon Monoxide	(CO)	140	70
$C_{organic}$ (5)		28	15
Metals			
Total Class I (4)		0.3	0.2
Mercury	(Hg)		
Cadmium	(Cd)		
Thallium	(Tl)		
Total Class II (4)		1.4	1.0
Arsenic	(As)		
Chromium	(Cr)		
Cobalt	(Co)		
Nickel	(Ni)		
Selenium	(Se)		
Tellurium	(Te)		
Total Class III (4)		7.0	5.0
Antimony	(Sb)		
Lead	(Pb)		
Cyanide	(CN)		
Copper	(Cu)		
Manganese	(Mn)		
Vanadium	(V)		
Beryllium	(Be)	--	0.14
Zinc	(Zn)	--	5.0

Notes:
1. All values corrected to 50% excess air, (7% O_2) dry and at 0^oC and 760 mm mercury.
2. Expected maximum emissions are expressed on the same basis as German Regulations (Ref: TA Luft[43]) wherein:
   - Values are 24 hour averages.
   - 97% of the half hour averages must not exceed the 24 hour average by more than 20%.
   - None of the half hour averages shall exceed the 24 hour average by more than a factor of two.
3. Expected typical values are expressed as half-hour averages.
4. Metal classes and the emission values for them are based on TA Luft (Ref: 43).
5. Organic carbon as determined by the Flame Ionization Detection method.

Destruction and Removal Efficiency (DRE) is a term that was introduced by the US Environmental Protection Agency (Ref: USEPA[44]) in order to measure the capability of an incineration system to destroy and remove certain predetermined organic chemicals. DRE relates the amount of a chemical fed to an incinerator to the amount of the same chemical leaving the incinerator through the stack using the following formula:

$$DRE = \frac{(W_{in} - W_{out})}{W_{in}} \times 100\%$$

Where:

W_{in} = Mass feed rate of a principal organic hazardous constituent (POHC) in the waste stream feeding the incinerator, and

W_{out} = Mass emission rate of the same POHC present in the flue gases discharged to atmosphere.

By definition, any quantity of the POHC discharged from the system with slag, ash or salt is considered removed. Some rotary kiln incinerators which operate at lower temperatures than that proposed for OWMC's Facility, may achieve high DREs while still discharging significant quantities of the POHC in the kiln residue. OWMC's design mitigates this possibility by operating in the slagging mode wherein the organic content of the kiln residue is extremely low, as further addressed in Section 4.5.2 (pg. 218).

Also by definition, a POHC is considered destroyed even if the molecule is split to form another equally or more hazardous chemical. The new chemical, - often referred to as a product of incomplete combustion (PIC), is nevertheless considered as an organic emission when detected in the treated flue gases. Dioxins and furans fall into this category.

The US Environmental Protection Agency has established a minimum 99.99% DRE requirement for POHCs. These POHCs are selected independently for each installation based on the types of waste to be incinerated (Ref: USEPA[44,45]). Additionally the US Environmental Protection Agency requires incinerators used to destroy non-liquid PCBs to meet a mass air emission rate of 0.001 g/kg/ of PCBs introduced into the incinerator, which translates into a DRE of 99.9999%. Incinerators used to destroy liquid PCBs must among other requirements meet specifications for temperature, residence time and excess oxygen in the stack gas all of which are predicated on achieving a DRE of 99.9999%.

Destruction and removal efficiencies (DREs) have been determined for various organic species at similar rotary kiln incineration facilities to that proposed by OWMC (Ref: Gorman[27], Maurer[42], Von Roll[46]).

Available data suggests that a DRE of 99.99% can be consistently achieved for all POHCs reported although occasional results below this value are indicated. For example, an analysis of data reported by Gorman [27] on the SCA Facility in Chicago shows the following, based on six test runs on each of ten POHCs:

POHC	Range %	Comment
Benzene	99 - 99.998	4 out of 6 results above 99.99%
Carbon tetrachloride	99.999 - 99.999995	All results above 99.999%
Chloroform	99.99 - 99.9997	All results above 99.99%
Methylene Chloride	99.999 - 99.9998	All results above 99.999%
Tetrachloroethylene	99.9997 - 99.9999	All results above 99.999%
Toluene	99.9994 - 99.9999	All results above 99.999%
1,1,1-Trichloroethane	99.9997 - 99.999998	All results above 99.999%
Trichlorethylene	99.9993 - 99.9999	All results above 99.999%
Hexachlorocyclopentadiene (C_{56})	99.998 - 99.99998	All results above 99.998%
Octachlorocyclopentene (C_{58})	99.999 - 99.99999	All results above 99.999%

Four test runs on the destruction of PCBs included PCB feed rates ranging from 189 kg/h to 1062 kg/h and average waste feed chlorine contents ranging from 21.4% to 28.5%. The DRE for PCBs ranged from 99.99995% to 99.99999% for all four runs.

Maurer reported DREs for PCBs at HIM Biebesheim always greater than 99.999% over several tests (Ref: Maurer[42]), whereas results reported from the SAKAB Facility in Sweden and Kommunekemi Facility in Denmark showed DREs of 99.9999% and 99.9998 respectively (Ref: Von Roll[46]).

On this basis a treatment objective has been adopted that all POHCs be destroyed at a DRE of at least 99.99% and that PCBs should be destroyed at a DRE of at least 99.9999% which is believed consistent with the protection of public health. If a subsequent health risk analysis concludes that greater DREs are necessary to protect public health, current treatment objectives would be modified, within practical limits.

Specific Emission Data

An increasing amount of data exists on the emissions of organic compounds from rotary kiln incineration systems of this type.

Specific emission data from HIM Biebesheim, West Germany and the SAKAB Facility in Sweden illustrates that the organic compounds discharged from incinerators of this type contain literally hundreds of organic species in extremely small concentrations. Also, that the sum total of the total organic carbon contained in these organic species represents a small emission, normally in the range 6 - 28 mg/Nm^3 dry, at 50% excess air. (Ref: Maurer[42]).

A great deal of information is becoming available on emissions of polychlorinated dibenzodioxins (PCDD) and polychlorinated dibenzofurans (PCDF) from incinerators identical to the type proposed by OWMC. Results from the SAKAB facility in Sweden (Ref: Oberg[47,48,49]) and HIM Biebesheim (Ref: Maurer[50]) provide the following information obtained over several test periods.

PCDD/PCDF Compound Species	HIM Maximum Concentration in **Treated** Flue Gas ng/m^3	SAKAB Concentrations in **Raw** Flue Gas Mean ng/m^3	SAKAB Concentrations in **Raw** Flue Gas Standard Deviation ng/m^3
Tetra-CDD	1.1	1.9	1.8
Penta-CDD	0.8	18.0	25.0
Octa-CDD	17.5	-	-
Tetra-CDF	16.2	24	35
Penta-CDF	8.9	48	29
Octa-CDF	17.5	-	-

The SAKAB data is based on eleven samples. It should be noted that the values for SAKAB are for the raw flue gas prior to treatment and tests have demonstrated removal efficiencies of more than approximately 50% for PCDD and more than 65% for PCDF in the flue gas treatment system, based on mean values for various isomer groups. (Ref: Moller[38], Oberg[48]). Similar removal efficiencies have been recorded at HIM Biebesheim (Ref: Maurer[50]). Hence, the concentration of dioxins and furans in the treated flue gases of these facilities are similar, and one to three orders of magnitude lower than reported values from municipal garbage incinerators operating in Ontario (Ref: Ozvacic[51]).

Absolute Emissions

The absolute quantities of various contaminants which are expected to be discharged from OWMC's Incineration plant annually, are shown on Table 5. Values are for the initial single incinerator installation having a nominal capacity of 30 000 t/a.

These quantities of contaminants are small when compared with industry at large, and exceedingly small when compared with heavy industry sectors such as metal smelting, and also electrical power generation using fossil fuels. For example, the Ministry of the Environment has indicated that in 1985 alone, three metal companies and Ontario Hydro together emitted 1.2 million tonnes of sulphur dioxide, compared to approximately 24 t/a typically expected from OWMC's incineration plant.

Compliance with Ontario Regulations and Risk Analysis

Previous sections of this report have explained how technologies for the incineration plant have been selected to meet OWMC's goals and planning principles. The approach adopted has been to select best available proven technologies and to optimize the design of the resultant incineration process system to attain the lowest achievable contaminant discharge levels. At no time has there been any intent to solely meet Ontario's Regultions although such regulations are at all times a minimum standard to be achieved.

Ontario Regulations are nevertheless an important benchmark against which predicted emissons from OWMC's Facility should be compared in order to verify compliance and also to determine, on a comparative basis, how well OWMC's Facility will treat special wastes.

Studies currently being conducted by Environ Corporation and Ontario Research Foundation (Executive Summary p. xv) to investigate health risks and compliance with Ontario Regulations respectively, are basing their work on data provided by OWMC's Incineration Technology Consultants, as presented in Table 5 (pg. 219), published data on achievable destruction and removal efficiencies, together with other published data on specific emissions. Some of this data has been referenced in preceeding paragraphs while a more detailed accounting is provided in the Facility Description report (Ref: Monenco[5]).

4.5.2 SOLID RESIDUES

The residues which will be produced by OWMC's incineration plant are slag from the rotary kiln and a mixture of boiler ash and salt from the flue gas treatment system. The relative quantity of boiler ash in the ash/salt mixtures will be small.

All of these residues are in solid form and an impression of their chemical constituents is provided by data presented in Table 6, Slag Analyses from European Rotary Kiln Incineration Plants and Table 7, Analysis of Salt/Ash from HIM Biebesheim, (West Germany).

TABLE 5

EXPECTED QUANTITIES OF CONTAMINANTS DISCHARGED TO ATMOSPHERE

		Expected Typical Emission t/a (1,2)	
Particulates		2.36	
Hydrogen Chloride	(HCl)	2.36	
Sulphur Dioxide	(SO_2)	23.62	
Hydrogen Fluoride	(HF)	0.16	
Nitrogen Oxide	(NO_x)	31.50	
Carbon Monoxide	(CO)	11.0	
$C_{organic}$ (3)		2.36	
	Total	73.36	
Class I Metals (Hg, Cd, TL)		0.03	Included in quantity shown for particulates
Class II Metals (As, Cr, Co, Ni, Se, Te)		0.16	
Class III Metals (Sb, Pb, CN, Cu, Mn, V)		0.79	
Beryllium	(Be)	0.02	
Zinc	(Zn)	0.79	

Notes:

1. Emissions are based on a single 30 000 t/a incineration plant. Quantities should be doubled for an ultimate Facility capacity handling 60 000 t/a of organic waste.

2. Emissions based on expected typical emissions from OWMC's incineration plant, identified in Table 4.

3. Organic carbon as determined by the Flame Ionization Detection method.

TABLE 6

SLAG ANALYSES FROM EUROPEAN ROTARY KILN INCINERATION PLANTS

	Kommunekemi, Nyborg Denmark %		HIM, Biebesheim Germany %		SAKAB, Norrtorp Sweden %	
	Sample 1	Sample 2	Sample 1	Sample 2	Sample 1	Sample 2
Oxides:						
Fe_2O_3	52.8	47.45	27.57)	69.19	38.9	76.44
SiO_2	24.9	29.27	41.37)		12.5	5.0
TiO_2	7.8	7.5	2.35	5.0	30.0	in Fe_2O_3
Al_2O_3	5.22	3.01	11.94	5.0	9.6	10.0
CaO			6.83	8.0	4.3	0.75
Na_2O	3.0	2.0	2.97	5.0	-	0.5
MgO	1.57	1.92	1.82	3.0	-	0.5
BaO			-	2.0	3.8	3.0
CuO		3.0	-	1.0		0.03
K_2O	0.49	0.53	1.02	0.5		0.1
MnO	0.36	0.20	0.16	0.5		0.3
Cr_2O_3			3.94	0.2		3.0
SrO			-	0.2		0.01
MoO_3				0.2		0.003
NiO				0.1		0.2
SnO_2				0.05		0.05
ZnO				0.03		0.1
CoO	4.3	2.91		0.01		0.1
PbO				0.01		0.2
B_2O_3				0.005		-
ZrO_2				0.002		0.03
Ag_2O				0.001		-
V_2O_5				0.002		0.01
P_2O_5	1.28	2.05	1.78	-		-

Note:

1. Information provided by Environmental Elements Corporation and Von Roll Ltd.
2. Organic carbon is less than 1% when rotary kiln is operating in the slagging mode.
3. All analyses are provided as typical only for each facility.
4. The data presented in this table are the results of laboratory analyses of slag samples. Due to accuracy limitations of the analytical methods employed, columns may not total exactly 100%.

TABLE 7
ANALYSIS OF SALT/ASH FROM HIM BIEBESHEIM

	% by Weight	ppm by weight
Metals		
Aluminum	0.28	-
Barium	-	295
Boron	-	710
Cadmium	-	260
Calcium	13.0	-
Chromium	-	160
Copper	-	840
Iron	1.06	-
Lead	-	5 050
Magnesium	-	3 000
Manganese	-	160
Mercury	-	14.2
Nickel	-	135
Potassium	1.19	-
Sodium	15.0	-
Tin	-	840
Titanium	-	1 050
Vanadium	-	49.0
Zinc	-	9 300
Anions		
Bromide	14.5	-
Chloride	29.0	-
Nitrate	-	40
Sulphate	1.2	-
Organics		
Total Organic Carbon	-	4 080

Notes: (1) Analysis conducted by Zenon Environmental Inc.

(2) The data presented in this table cover only the metals (cations), anions, and organic carbon content which were analyzed.

The analyses are presented as typical of what can be expected from OWMC's Facility although it should be recognized that significant variations will occur in the percentages of individual constituents, depending on the nature and characteristics of waste being incinerated.

Slag will be disposed of directly in the engineered landfill whereas boiler ash and salt will be solidified prior to being sent to landfill.

REFERENCES

1. Generic Process Technologies Studies, The Proctor & Redfern Group, August 1982. 224 pp., Appendices.

2. Ontario Waste Management Corporation, Facilities Development Process Phase 1 Report, Assembly and Analysis of Primary Information on Engineering, Environmental and Planning Issues, OWMC, September 1982. 41 pp., Appendices.

3. Ontario Waste Management Corporation, Facilities Development Process Phase 3 Report, The Selection of Candidate Sites, OWMC, March 1984. 95 pp.

4. A.D. Little of Canada Limited, Rationale for the Selection of Technologies for the Treatment and Disposal of Special Wastes in Ontario - July 1985.

5. Monenco Limited, Facility Description, 1986.

6. Monenco Limited, Process Area Report - Physical/Chemical Treatment, 1986.

7. Monenco Limited, Process Area Report - Solidification, 1986.

8. Monenco Limited, Process Area Report - Landfill, 1986.

9. Monenco Limited, Process Area Report - General Facilities, 1986.

10. Ontario Waste Management Corporation, Facilities Development Process Phase 2 Report, Progress on the Selection of Facilities and Sites, OWMC, January 1983. 38 pp., Appendices.

11. Waste Quantities Study, The Proctor & Redfern Group with Weston Designers - Consultants and Ontario Research Foundation, August 1982. 68 pp., Appendices.

12. Regulation 308 (General - Air Pollution) R.R.O. 1980 under the Environmental Protection ACt, R.S.O 1980 as amended by S.O. 1981, C.49 and S.O. 1983, C. 52. (Includes standards, ambient air quality criteria, tentative standards, guidelines and provisional guidelines for air contaminants). Ministry of the Environment.

13. Power Magazine Special Report, SO_2 Control: Optimizing Today's Processes for Utility and Industrial Powerplants, October 1982.

14. Power Magazine, Developments to Watch (page 112), Vol. 128, No. 6, June 1984.

15. Power Magazine, Developments to Watch (page 107), Vol. 128, No. 6, September 1985.

16. Power Magazine, Developments to Watch (page 82), Vol. 128, No. 6, January 1985.

17. Scharsach A., The Regional Treatment Facility for Organic Hazardous Waste of the State of Hesse in Biebesheim, Germany, Presentation to Pennsylvania Academy, July 1983.

18. Lee, G.K., Control of NO_x Emissions from Pulverized - Coal Flames. Canada Centre For Mineral and Energy Technology, Energy Research Laboratories, Division Report ERP/ERL 83-27 (OP)(TR).

19. Gaudreau, M., Stefanoni, A., Design and Operation of the New Air Pollution Control System for the Montreal Incinerator, 12th APCA Quebec Annual Meeting, May 1984.

20. Shimell, P. M., Using Lime Reduces Dust in Flue Gases, World Wastes,

21. Sloan, W. M., Report on the First International Symposium on European Hazardous Waste Facilities and the Post - Symposium Facilities Tour, December 1982. (Maryland USA Hazardous Waste Facilities Siting Board).

22. Scharsach, A., Incinerator Emission Control Technology - Present and Future Processes, Energo 83, Ontario Energy Opportunitites in Biomass, March 1983.

23. Redhead, R. J., Hazardous Waste Incineration/Treatment, presented at the Government Refuse Collection and Disposal Association, Fifth Ontario Workshop on Waste Management, Ottawa, October 1983.

24. European Tour Report, prepared for OWMC by Proctor & Redfern, September 1982.

25. Fabian, H. W., Reher P., Schoen M., How Bayer Incinerates Wastes, Hydrocarbon Processing, April 1979.

26. Brenner, K. S. et al, Dioxin Analysis in Stack Emissions and in the Wash Water Circuit During High-Temperature Incineration of Chlorine - Containing Industrial Waste, Bulletin of Environmental Contamination & Toxicology, Nov. 1983.

27. Gorman, P.G., Hennon, G.J., Kush, G.S., Summary of Trial Burn Results at the SCA Incinerator, Paper #84-9.2 presented at the 77th Annual Meeting of the Air Pollution Control Association, San Francisco, 1984.

28. Kristensen, A., Rotary Kiln Incinerators for Organic Chemical Wastes, First International Symposium on Operating European Centralized Hazardous Waste Management Facilities, Odense, Denmark, 1982.

29. Vereinigte Kesselwerke AG (V.K.W.) Project Brochure for Industrial Incineration Plant at Ford Werke AG, Köln, West Germany.

30. Watson, R. H., Burnett J. M., Recent Developments and Operating Experience with British Incinerator Plant, ASME National Incinerator Conference, New York, 1972.

31. Whitehead, C., Darby, K., Cleaning of Gases from the Incineration of Waste Materials, Institute of Fuel Conference on the Incineration of Municipal and Industrial Waste, Brighton, England, November 1969.

32. Bastian, R. E., Seeman W. R., The Design and Operation of a Chemical Waste Incinerator for the Eastman Kodak Company.

33. Barter, J., Incineration and Recycling of Dangerous Industrial Organic Wastes at SERDOQ, 1st Conference on Toxic Substances, Montreal, Quebec, April 1984.

34. Acurex Final Report FR-85-153 A/EED, Environmental Assessment of the Texas Eastman Hazardous Waste Incinerator, Prepared for Texas Eastman Company for Submission to the Texas Air Control Board, February 1985.

35. Ceilcote Canada, Product Installation List for IWS™ System.

36. Dresser Industries, Fluid - Ionic Systems, Product Installation List for Wet Electrostatic Precipitators.

37. Orkild, P., Dry Scrubbing of Flue Gases from Chemical Waste Incinerators. First International Symposium on Operating European Centralized Hazardous Waste Management Facilities, Odense, Denmark, September 1982.

38. Moller, J.T., Christiansen O.B., Dry Scrubbing of MSW Incinerator Flue Gas by Spray Dryer Absorption: New Developments in Europe. 78th Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 1985.

39. Power Magazine, Match Bag Material for your Fabric Filter to type of Service, Vol. 127, No. 10, October 1983.

40. Number not used.

41. Number not used.

42. Maurer, P.G. et. al. Report on the Hazardous Waste Treatment Plant of The Hessian Industrial Waste, Inc., (HIM) in Biebesheim Germany), U. S. Environmental Protection Agency, Investigation Report Environmental Research, 180 pp., September 1984.

43. TA Luft Air Quality Regulations, Federal Republic of Germany, 1983. Erste Allgemeine Verwaltungsvorschrift zum Bundes - Immissions schutzgesetz (Technische Anleitung zur Reinhaltung der Luft - TA LUFT) vom 15.Dezember 1983.

44. U.S. Environmental Protection Agency, Incinerator Standards for Owners and Operators of Hazardous Waste Management Facilities, Federal Register Vol. 46, No. 15, 23 January 1981, Rules & Regulations and Volume 47, No. 122, 24 June 1982.

45. U.S. Environmental Protection Agency, Ranking of Incinerability of Organic Hazardous Constituents, from Appendix VIII, Part 261, On the Basis of Heat of Combustion (Table 2-8) (Full Reference Required).

46. Von Roll Document on PCB - Incineration, Prepared for OWMC, Edition 1.1, November 1984.

47. Oberg, T. Health Risk Evaluation of Flue Gas Emissions of Chlorinated Dioxins and Dibenzofurans from a Hazardous Waste Incineration Plant, MKS Technical Report MKS-84/38. Environmental Consultants at Studsvik AB, September 1984.

48. Oberg, T. et. al. Chlorinated Aromatics from the Combustion of Hazardous Waste. Environmental Consultants at Studsvik AB S-61182, Nykoping, Sweden, Chemosphere Vol. 14, No. 2, pp. 215 - 221, 1985.

49. Oberg, T., Bergstrom, J. Combustion Test Data from a Swedish Hazardous Waste Incinerator. MKS Technical Report MKS-85/73A. Environmental Consultants at Studsvik AB. Presented at 5th International Symposium on Chlorinated Dioxins and Related Compounds, Bayreuth, West Germany, September 1985.

50. Maurer, P.G., Gorgeny T., Co-Incineration of Polychlorinated Biphenyls in the Hazardous Waste Incineration Plant in Biebesheim, Analytical Report prepared for Hessische Industriemüll GmbH, Wiesbaden, West Germany, (by Nukem GmbH, Hanau), June 1985.

51. Ozvacic, V. et. al. Emissions of Chlorinated Organics from Two Municipal Incinerators in Ontario, Journal of the Air Pollution Control Association, Volume 35, No. 8,August 1985.

GLOSSARY OF TERMS

Aqueous Organic Waste: Liquid waste which contains organics with significant proportions of water.

Basis of Design: The criteria on which the design of the treatment process or system is based, including incoming waste quantity and characteristics, treatment objectives, facility capacity, mode of operation, process reliability etc.

Boiler Blowdown: That portion of the water in the boiler's steam/water circulatory system that is discharged to maintain the concentration of total solids (dissolved and suspended) at predetermined levels.

Combustion: The process of converting inherent chemical energy in a substance to heat and light energy through oxidation at elevated temperatures.

DRE: Abbreviation for "Destruction and Removal Efficiency". It is a calculation method used by U.S. Environmental Authorities to determine an incineration system's efficiency of destroying and removing a given POHC. The calculation is defined by the following formula:

$$DRE = \frac{(W_{in} - W_{out})}{W_{in}} \times 100\%$$

Where W_{in} = Mass feed rate of a principal organic hazardous constituent (POHC) in the waste stream feeding the incinerator, and

W_{out} = Mass flow rate of the same POHC in the gases discharged to atmosphere

Flue Gases: The gaseous products of waste combustion.

Fly Ash: Particulate matter removed from flue gases. In the case of boiler fly ash the removal is the result of natural precipitation or settling out of such particles from the flue gases in their passage through the waste heat boiler. In the case of precipitator fly ash, the removal is the result of electrostatic precipitation.

HHV: Abbreviation for "Higher Heating Value". This is a measure of the total or gross heat energy that will be released during combustion of a substance. It is determined by measuring the amount of heat recovered when the products of complete combustion for a unit quantity of a substance are cooled to the initial temperature of the substance and the ambient air.

Incineration: The thermal destruction of waste by oxidation at elevated temperatures.

Inorganic Waste: Waste predominantly composed of inorganic materials such as naturally occurring minerals.

LHV: Abbreviation for "Lower Heating Value". A measure of the net (useful) amount of energy released during the combustion of a unit quantity of a substance. It is equal to the HHV less the latent heat of the moisure contained in the products of combustion.

Organic Waste: Waste predominantly composed of elements that are oxidizable and therefore capable of thermal destruction by incineration. Organic materials originate from living things such as trees, animals etc.

Oxidation: A chemical reaction where molecules or atoms of oxygen are combined with molecules or atoms of another substance. In this report oxidation is always used to represent oxidation at elevated temperatures, i.e. thermal oxidation.

Particulate (Dust): Solid material entrained in the flue gas.

Physical/Chemical Treatment Processes: Physical/chemical treatment processes commonly refer to processes whose main operating principles involve either physical treatment, chemical treatment or some combination of both physical and chemical treatment.

POHC: Abbreviation for "Principal Organic Hazardous Constituents". This is the name given to a substance if it is contained in a listing of specified compounds in U.S. Environmental Legislation. POHCs are typically the more difficult to thermally destruct constituents of hazardous substances.

Products of Combustion: Products of the combustion process other than the heat and light energy released. These products include flue gases and any solid residues.

Raw Flue Gases: Refers to flue gases which contain contaminants such as acid gases and/or particulate matter, prior to their removal in a flue gas treatment system.

Residue: Solids, semi-solid or liquid materials remaining after incineration or organic waste and physical/chemical treatment of inorganic wastes, or as a waste product of other processes.

Scrubber Effluent: That portion of the water or solution in the wet scrubber component of the flue gas treatment system which is discharged to maintain the concentration of dissolved solids at predetermined levels. This same scrubber effluent becomes spray dryer feed.

Slag: A solid product of combustion that exists in the rotary kiln in the molten state. It is composed of inerts and other chemical elements that will not oxidize such as silica contained in soils or the steel from drums. The liquid slag is solidified by quenching in a water bath.

Solidification: The process by which chemically reactive formulations and components in the waste form stable solids which will not revert to the original liquid or semi-liquid state under conditions anticipated in the landfill.

Stack: The vertical structure that contains the cylindrical duct or flue used to convey and discharge the cleaned flue gases to atmosphere.

System: The assembly of equipment, piping, instruments, electrics, foundations and structures into an installation in which process treatment is executed.

Treated Flue Gases: Refers to the cleaned flue gases after they have been treated for the removal of contaminants.

APPENDIX A

TECHNOLOGY EVALUATION

APPENDIX A

This appendix should be read in conjunction with Section 3.3 Criteria for Technology Selection, which defines the criteria, weightings and how these criteria have been utilized in the evaluation of alternative technologies.

It may assist the reader to be aware that for brevity's sake, only those characteristics of a technology or system that play a role in determining its points score for a particular criteria, are included in the tables. This applies to all the evaluation criteria.

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	• Good Particulate, Acid Gas and Metal Removal (5) (50)	• Good Particulate, Acid Gas and Metal Removal (5) (50)	• Good Particulate Acid Gas and Metal Removal (5) (50)	• Good Particulate Acid Gas and Metal Removal (5) (50)
EFFICIENCY - ENERGY, UTILITIES, REAGENTS	2	• Median Energy Use • Median Water Use • Median Reagent Use (3) (6)	• Higher Energy Use due to larger flue gas quantity • Median Water Use • Median Reagent Use (2) (4)	• Higher Energy Use due to larger flue gas quantity • Highest Water Use due to gas cooling • Median Reagent Use (1) (2)	• Median/higher Energy use due to spray dryer pressure loss • Low Water Use due to two stage scrubbing • Median Reagent Use, but lower cost due to reduced use of caustic soda (4.5) (9)
RESIDUE CHARACTERISTICS	2	• Boiler/Flyash Removed Dry • Scrubber Effluent Requires Phys/Chem Treatment (Evaporate and Solidify) (1) (2)	• Boiler/Flyash Removed Dry • Scrubber Effluent Requires Phys/Chem Treatment (Evaporate and Solidify) (1) (2)	• Potential for Concentrated Dry Residue • Solidification Treatment • Excess Effluent to Phys/Chem (3) (6)	• Concentrated Dry Residue • Solidification Treatment (5.0) (10)
EXTENT USED ELSEWHERE	6	• Extensive Experience (5) (30)	• Extensive Experience (5) (30)	• Limited Experience on Industrial Facilities • Uncertainty regarding use of Scrubber Effluent in Cooling Tower (2) (12)	• Good Experience (4) (24)
SUB-TOTAL - PERFORMANCE		**(88)**	**(86)**	**(70)**	**(93)**

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4
SAFETY					
OCCUPATIONAL RISK	10	o On-line boiler cleaning (4.5) (45)	o No on-line boiler cleaning (5) (50)	o No on-line boiler cleaning (5) (50)	o On-line boiler cleaning a minor concern (4.5) (45)
ENVIRONMENTAL RISK	10	o Safe During Normal Conditions o Safe During Upset Conditions o Automatic Safety Systems o Partial Scrubbing of Gas During Power Failure (4) (40)	o Safe During Normal Conditions o Safe During Upset Conditions o Automatic Safety Systems o Partial Scrubbing of Gas During Power Failure (4) (40)	o Safe During Normal Conditions o Safe During Upset Conditions o Automatic Safety Systems o Partial Scrubbing of Gas During Power Failure (4) (40)	o Safe During Normal Conditions o Safe During Upset Conditions o Automatic Safety Systems o Partial Scrubbing of Gas During Power Failure (4) (40)
SUB-TOTAL - SAFETY		**(85)**	**(90)**	**(90)**	**(85)**
FLEXIBILITY					
WASTE CHARACTERISTICS	7	o Good Flexibility in Design Range (5) (35)	o Good Flexibility in Design Range (5) (35)	o Good Flexibility in Design Range (5) (35)	o Good Flexibility in Design Range (5) (35)
WASTE QUANTITIES (INCLUDES PROCESS TURNDOWN)	7	o High Turndown Capability (5) (35)	o High Turndown Capability (5) (35)	o High Turndown But Possible Constraint on Cooling Tower Sprays (4.5) (31.5)	o High Turndown But Possible Constraint on Spray Dryer Capacity at High Acid Gas Concentrations (4.5) (31.5)
RAPID STARTUP/SHUTDOWN		ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUB-TOTAL - FLEXIBILITY		**(70)**	**(70)**	**(66.5)**	**(66.5)**

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4
RELIABILITY					
MAINTENANCE REQUIRED	1	• Low (4) (4)	• Low (4) (4)	• Low (4) (4)	• Medium due to additional process component (3) (3)
SPARE PARTS	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
AVAILABILITY OF SPARES/REAGENTS	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
ROBUSTNESS OF EQUIPMENT	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	• 3 Components (Excl. Incinerator) (4) (32)	• 3 Components (Excl. Incinerator) (4) (32)	• 3 Components (Excl. Incinerator) (4) (32)	• 4 Components (Excl. Incinerator) (3.5) (28)
SUB-TOTAL - RELIABILITY		(36)	(36)	(36)	(31)
OPERATIONS					
COMPLEXITY	6	• Medium (4) (24)	• Medium (4) (24)	• Medium (4) (24)	• High due to additional component (3.5) (21)
DEGREE OF AUTOMATION	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
STARTUP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUB-TOTAL - OPERATIONS		(24)	(24)	(24)	(21)

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4
COMMERCIAL & ECONOMICS					
RESTRICTIONS ON USE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
COST	7	• Median Capital Cost • Median Operating Cost • Median Overall Cost (2) (14)	• Median Capital Cost • Median Operating Cost • Median Overall Cost (2) (14)	• Lowest Capital Cost • Low Operating Cost • Low Overall Cost Providing Scrubber Effluent can be Disposed of in Cooling Tower (3) (21)	• Highest Capital Cost • Very Low Operating Cost • Lower Overall Cost (4.0) (28)
SUPPLIER COMPETITION AND RELIABILITY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
DELIVERY	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUB-TOTAL - COMMERCIAL & ECONOMICS		(14)	(14)	(21)	(28)
CANADIAN/ONTARIO BENEFITS					
ENGINEERING	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUPPLY AND FABRICATION	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
LONG TERM TECHNOLOGY TRANSFER	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUB-TOTAL - CANADIAN/ONTARIO BENEFITS		ALL PROCESSES ARE JUDGED TO BE EQUAL			
GRAND TOTAL		(317)	(320)	(307.5)	(324.5)

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 5	ALTERNATIVE 6	ALTERNATIVE 7	ALTERNATIVE 8
PERFORMANCE					
MOST EFFECTIVE TREATMENT	10	• Marginal Particulate Removal Capability Compared to Other Alternatives • Good Acid Gas and Metal Removal (3.5) 35)	• Good Particulate, Acid Gas and Metal Removal (5) (50)	• Good Particulate, Acid Gas and Metal Removal (5) (50)	• Good Particulate, and Metal Removal • Acid Gas Removal Poor at High Inlet Concentrations. Does not Meet Minimum Performance Requirements. (0) (0)
EFFICIENCY - ENERGY, UTILITIES, REAGENTS	2	• Higher Energy Use due to scrubber pressure loss • Median Water Use • Median Reagent Use (2) (4)	• Median Energy Use • Median Water Use • Median Reagent Use but higher cost due to greater use of caustic soda (2) (4)	• Median Energy Use • Median Water Use • Median Reagent Use (3) (6)	• Low Energy Use • Lowest Water Use due to Semi-Dry Scrubbing • Median Reagent Use but lowest cost due to use of lime (5) (10)
RESIDUE CHARACTERISTICS	2	• Flyash Removed with Scrubber Effluent • Requires Phys/Chem Treatment (Metals Removal, Evaporate, Solidify) (1) (2)	• Flyash Removed with Scrubber Effluent • Requires Phys/Chem Treatment (Metals Removal, Evaporate, Solidify) • High Quantity (0) (0)	• Flyash Removed with Scrubber Effluent • Requires Phys/Chem Treatment (Metals Removal, Evaporate, Solidify) (1) (2)	• Concentrated Dry Residue • Solidification Treatment (5) (10)
EXTENT USED ELSEWHERE	6	• Extensive Experience (5) (30)	• Extensive Experience (5) (30)	• Limited (Uncertain) Experience (3) (18)	• Good Experience with Electrostatic Precipitator, Limited with Fabric Filter (3) (18)
SUB-TOTAL - PERFORMANCE		**(71)**	**(84)**	**(76)**	**(38)**

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 5	ALTERNATIVE 6	ALTERNATIVE 7	ALTERNATIVE 8
SAFETY					
OCCUPATIONAL RISK	10	• On-line boiler cleaning a minor concern (4.5) (45)	• On-line boiler cleaning a minor concern (4.5) (45)	• On-line boiler cleaning a minor concern (4.5) (45)	• On-line boiler cleaning a minor concern (4.5) (45)
ENVIRONMENTAL RISK	10	• Safe During Normal Conditions • Safe During Upset Conditions • Automatic Safety Systems • Partial Scrubbing of Gas During Power Failure (4) (40)	• Safe During Normal Conditions • Safe During Upset Conditions • Automatic Safety Systems • Partial Scrubbing of Gas During Power Failure (4) (40)	• Safe During Normal Conditions • Safe During Upset Conditions • Automatic Safety Systems • Partial Scrubbing of Gas During Power Failure (4) (40)	• Safe During Normal Conditions • Safe During Upset Conditions • Automatic Safety Systems • Partial Scrubbing of Acid Gases During Power Failure • Continued Scrubbing of Particulates and Metals During Power Failure (5) (50)
SUB-TOTAL - SAFETY		(85)	(85)	(85)	(95)
FLEXIBILITY					
WASTE CHARACTERISTICS	7	• Good Flexibility in Design Range • Possible Susceptibility to High Particulate Concentrations (4) (28)	• Good Flexibility in Design Range • Possible Susceptibility to High Particulate Concentrations (4) (28)	• Good Flexibility in Design Range • Possible Susceptibility to High Particulate Concentrations (4) (28)	• Constrained Flexibility at High Acid Gas Contaminant Loadings (2) (14)
WASTE QUANTITIES (INCLUDES PROCESS TURNDOWN)	7	• High Turndown Capability (5) (35)	• High Turndown Capability (5) (35)	• High Turndown Capability (5) (35)	• Significant Turndown Constraint due to Reduced Spray Dryer Thermal Capacity (3.5) (24.5)
RAPID STARTUP/SHUTDOWN		ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUB-TOTAL - FLEXIBILITY		(63)	(63)	(63)	(38.5)

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 5	ALTERNATIVE 6	ALTERNATIVE 7	ALTERNATIVE 8
RELIABILITY		• Lowest due to least process components	• Medium due to two wet scrubber components	• Medium due to two wet treatment components	• Low
MAINTENANCE REQUIRED	1	(5) (5)	(3) (3)	(3) (3)	(4) (4)
SPARES	2	ALL PROCESSES ARE JUDGED TO BE EQUAL			
AVAILABILITY OF SPARES/REAGENTS	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
ROBUSTNESS OF EQUIPMENT	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
VULNERABILITY TO PROCESS UPSETS OR BREAKDOWNS	8	• 2 Components (Excl. Incinerator) (4.5) (36)	• 3 Components (Excl. Incinerator) (4) (32)	• 3 Components (Excl. Incinerator) (4) (32)	• 3 Components (Excl. Incinerator) (4) (32)
SUB-TOTAL - RELIABILITY		(41)	(35)	(35)	(36)
OPERATIONS		• Low, least number of components	• Medium	• Medium	• Low, no wet scrubber
COMPLEXITY	6	(5) (30)	(4) (24)	(4) (24)	(5) (30)
DEGREE OF AUTOMATION	3	ALL PROCESSES ARE JUDGED TO BE EQUAL			
STARTUP ASSISTANCE	1	ALL PROCESSES ARE JUDGED TO BE EQUAL			
SUB-TOTAL - OPERATIONS		(30)	(24)	(24)	(30)

TABLE A-1
EVALUATION OF ALTERNATIVE ROTARY KILN INCINERATION PROCESS SYSTEMS

CRITERIA / ALTERNATIVE	WEIGHT	ALTERNATIVE 5	ALTERNATIVE 6	ALTERNATIVE 7	ALTERNATIVE 8
COMMERCIAL & ECONOMICS					
RESTRICTIONS ON USE	1		ALL PROCESSES ARE JUDGED TO BE EQUAL		
COST	7	• Low Capital Cost • Median Operating Cost • Median Overall Cost (2) (14)	• High Capital Cost • High Operating Cost • Highest Overall Cost (0) (0)	• Median Capital Cost • Median Operating Cost • Median Overall Cost (2) (14)	• Low Capital Cost • Lowest Operating Cost • Lowest Overall Cost (5) (35)
SUPPLIER COMPETITION AND RELIABILITY	1		ALL PROCESSES ARE JUDGED TO BE EQUAL		
DELIVERY	1		ALL PROCESSES ARE JUDGED TO BE EQUAL		
SUB-TOTAL - COMMERCIAL & ECONOMICS		(14)	(0)	(14)	(35)
CANADIAN/ONTARIO BENEFITS					
ENGINEERING	1		ALL PROCESSES ARE JUDGED TO BE EQUAL		
SUPPLY AND FABRICATION	2		ALL PROCESSES ARE JUDGED TO BE EQUAL		
LONG TERM TECHNOLOGY TRANSFER	2		ALL PROCESSES ARE JUDGED TO BE EQUAL		
SUB-TOTAL - CANADIAN/ONTARIO BENEFITS			ALL PROCESSES ARE JUDGED TO BE EQUAL		
GRAND TOTAL		(304)	(291)	(297)	(272.5)

APPENDIX B

TECHNICAL DATA ON ALTERNATIVE SYSTEMS

APPENDIX B
TECHNICAL DATA ON ALTERNATIVE SYSTEMS

	Units	ALTERNATIVES 1	2	3	4	5	6	7	8
COMBUSTION SYSTEM									
Waste Quantity	kg/h	4 760	4 760	4 760	4 760	4 760	4 760	4 760	4 760
Combustion Air	kg/h	43 160	43 160	43 160	43 160	43 160	43 160	43 160	43 160
Outlet Gas Temperature	°C	1 100	1 100	1 100	1 100	1 100	1 100	1 100	1 100
FLUE GAS COOLING SYSTEM									
Cooling Air	kg/h	-	21 280	-	-	-	-	-	-
Outlet Gas Temperature	°C	250	250	250	525	250	250	250	525
Steam Generated	kg/h	20 900	17 500	-	14 500	20 900	20 900	20 900	14 450
Cooling Water	kg/h	-	-	18 730 (if req'd)	-	-	-	-	-
FLUE GAS TREATMENT SYSTEM									
Gas Quantity in	Nm^3/h	37 300	53 900	56 250	37 300	37 300	37 300	37 300	37 300
Water Required	kg/h	20 680	22 130	22 800	9 540	20 680	26 500	20 450	6 850
Reagent Quantity									
- NaOH (100%)	kg/h	550	550	550	380	550	970	360	-
- CaO (100%)	kg/h	500	500	500	700	500	140	570	915
Liquid Effluent	kg/h	18 730	18 730	(18 730)	-	18 730	24 600	18 500	-
Dry Residue	kg/h	200	200	-	1 940	-	-	-	1 760
Stack Gas									
- Quantity	Nm^3/h	49 900	59 650	64 660	48 350	41 250	41 250	41 250	46 000
- Particulates) 50%	mg/Nm^3	50	50	50	50	50	50	50	50
- HCl) Excess	mg/Nm^3	50	50	50	50	50	50	50	>1 000
- SO_2) Air (Dry)	mg/Nm^3	200	200	200	200	200	200	200	>1 000

Notes:

1. Based on 15% chlorine and 3% sulphur in waste.

No Effluent if sent to cooling tower.

2. Majority of this data based on preliminary process design by Monenco except liquid effluent and reagent quantities for proprietory equipment which was obtained from vendors.

APPENDIX C

COST DATA ON ALTERNATIVE SYSTEMS

COST DATA ON ALTERNATIVE INCINERATION SYSTEMS

BASIS AND METHODOLOGY

Capital, operating and maintenance cost estimates were established for each alternative system identified for detailed comparison in Chapter 3 of this report. The costs were used in an economic model to determine the approximate relative economic ranking of each alternative.

This Appendix C reflects work conducted by Monenco.

Capital Cost Estimates

A capital cost estimate was prepared for Alternative 1 (Base) using preliminary process flow diagrams, equipment lists and plant arrangement drawings as a basis. Budget prices were obtained from suppliers of flue gas treatment equipment, while remaining items were estimated using budget pricing information previously obtained for a similar project. Miscellaneous civil, mechanical and electrical items were estimated using Monenco in-house information.

Capital costs for other alternatives described in Chapter 3 were developed from the Base Estimate either by direct deletion or addition of pertinent components within the cost estimate, or by factoring components of the estimate for scale. Budget prices were obtained for all alternative flue gas treatment schemes. Budget prices were requested, but not obtained, for alternative designs of heat recovery boiler, and cost estimates were therefore based upon data obtained for a similar project, adjusted as necessary for size. It was assumed that a radiant boiler design would cost 50% more than a totally convective boiler design.

In developing the total installed cost for each case, an allowance of 15% of the direct field costs was included for EPCM services, and an overall allowance of 20% for contingency.

Overall estimate accuracy is estimated to be in the order of 25% although specific components may be substantially less accurate. All costs were computed in third quarter 1984 Canadian dollars.
(Note: This estimate was compiled in mid 1984.)

Operating and Maintenance Costs

Operating and maintenance cost estimates were prepared for each alternative incineration system described in Chapter 3, using information contained on preliminary process flow diagrams, supplemented as required by in-house data. The following establishes the basis for each component of the operating cost estimate.

Personnel

- Estimated personnel requirements were costed at $36 000/manyear (average).

Electrical Power

- Preliminary driver lists were prepared for each case together with estimated connected load and annual absorbed power requirements.
- Power costs were based on a demand charge of $2.8/kw of maximum demand per month, and energy charges were based on $0.0295/kwh.
- It was assumed that the incinerator is shut-down for 760 hours in the summer for annual turnaround and 1000 hours in the winter for forced outage.

Water

- Process water requirements were estimated based on average waste constituents of 5% chlorine and 1% sulphur, plus an allowance for boiler makeup water.
- Annual water charges were costed at $0.20/1000 litres.

Fuel Gas

- Auxiliary boiler fuel requirements were based on steam quantities taken from preliminary steam balances and an assumed boiler efficiency of 80%.

- It was assumed that the incinerator would be shut-down for 760 hours in the summer for annual turnaround and 1000 hours in the winter for forced outage.

- Incinerator fuel gas consumption was based on 200 hours/a at 800 m^3/h and 200 hours/a at 400 m^3/h and includes for refractory dryout and miscellaneous startups each year. No allowance was made for supplementary fuel as this would be common for all alternatives.

- No allowance is included for combustion air heating.

- Incinerator startup fuel requirements were reduced by 25% for Alternative 2 to allow for higher boiler availability. It was assumed that three annual shutdowns of four days each could be avoided. The auxiliary boiler fuel requirements were reduced by 288 hours/a at 80% full load capacity.

- Fuel gas was costed at \$0.18/Nm^3.

Chemicals

- Chemical requirements were derived from the preliminary process flow diagrams, based on process design conducted by Monenco with input from equipment suppliers. Design consumptions were adjusted to reflect average operating conditions at 5% chlorine and 1% sulphur in waste.

- NaOH was costed at \$460/t delivered to site (100% basis).

- CaO was costed at \$70/t delivered to site (100% basis).

Residue Disposal

- The quantity of solid residue for each case was based on waste having an average ash content of 15% by weight, plus any salts removed in solid form from the system.

- It was assumed that all solid residue is solidified prior to disposal in the landfill.

- The quantities of liquid effluent (blowdown) discharged from wet scrubber systems were based on average chlorine and sulphur levels of 5% and 1% by weight respectively in the waste. This effluent was assumed to be concentrated by multi-stage evaporation in the physical/chemical facility from 10% total dissolved solids to 20% total dissolved solids (50% volume reduction) and the concentrate solidified prior to disposal in the landfill.

- Cost of solidifying solid and liquid effluent was based on an "all-in" cost of $100/t.

Maintenance

- Annual plant maintenance costs were estimated on the following basis:

General equipment	-	4% Capital Cost/annum
Refractories - Kiln	-	100% Capital Cost/annum
- Secondary Chamber	-	20% Capital Cost/annum
Waste feed equipment	-	9% Capital Cost/annum
Residue handling equipment	-	9% Capital Cost/annum
Buildings and general civil works	-	1% Capital Cost/annum

Waste Quantities

- The waste quantities were assumed to be as follows:

Year 1	-	20 000 t/a
Year 2	-	20 000 t/a
Year 3	-	25 000 t/a
Year 4 (onwards)	-	30 000 t/a

- The ultimate capacity of the incineration system for Alternative 2 was assumed to be 4% greater than all other cases, to compensate for an improvement in boiler availability.

Economic Analysis

A life cycle costing approach was used whereby the year by year total Facility costs are determined and all restated by discounting or calculating present values in 1984 dollars. (Note this work was conducted in mid 1984.) This is equivalent to replacing the total costs over the lifetime of the Facility with one lump sum capital expenditure in 1984, which could be drawn down each year as the Facility costs are incurred.

The analysis includes assumptions regarding escalation rates, cost of capital, economic life of the facilities and other evaluation parameters, as summarized below. Income taxes and accelerated depreciation are not considered.

- Cost of Capital 12%
- Escalation rate 8% (equipment and labour)
- Construction period 2 years
- Construction costs incurred at start of each year (40% first year, 60% second year)
- Interest during construction included to capitalization date (first year of construction)
- Working capital equals 1-1/2 months of next years operating costs
- Operating costs incurred at end of each year
- Economic life 25 years
- Salvage value - zero
- Decommissioning costs - zero

Note: Differences between the basis of this economic evaluation and other OWMC reports reflect adjustments agreed with OWMC at different stages of the Facility Development Process.

COST COMPARISON

The differential capital and operating cost estimates for each alternative incineration system are presented in Tables C-1 and C-2 respectively.

The result of the comparative economic evaluation is as follows:

Alternative	Cost Ranking	Points (Max. 5)	
Alternative 8	lowest	5	
Alternative 4		4	
Alternative 3		3	(Note 1)
Alternative 7		2	(Note 2)
Alternatives 1, 2, 5		2	
Alternative 6	highest	0	

Note 1: The life cycle cost for Alternative 3 was only marginally more than for Alternative 4 assuming all scrubber effluent could be disposed of in the cooling tower. The lower points awarded reflects uncertainty whether all effluent could be disposed of in this manner.

Note 2: The life cycle cost for Alternative 7 was marginally less than for the group of Alternatives 1, 2 and 5. However, this Alternative was awarded the same points score, reflecting the uncertainty on whether operating costs for chemicals and residue disposal would in practice be significantly different from Alternative 1.

TABLE C-1
DIFFERENTIAL CAPITAL COST ESTIMATE SUMMARY
($1000)

DESCRIPTION	ALTERNATIVE 1	2	3	4	5	6	7	8
Buildings and Civil Works	Base	0	(300)	0	0	0	0	0
Waste Feed Systems	Base	0	0	0	0	0	0	0
Incinerator	Base	345	0	0	0	0	0	0
Heat Recovery Boiler	Base	(875)	(2 625)	(480)	0	0	0	(480)
Flue Gas Cooling Tower	Base	0	450	0	0	0	0	0
Flue Gas Treatment (incl. scrubber blowdown treatment)	Base	530	(245)	1 800	(425)	1 000	435	(120)
Ash Handling Systems	Base	0	(50)	50	(250)	(250)	(250)	50
Auxiliary Systems	Base	0	(280)	(50)	0	0	0	(50)
Miscellaneous Items (piping, electrical, controls, etc.)	Base	0	(355)	61	(50)	50	10	(46)
EPCM Services	Base	0	(510)	207	(109)	120	30	(96)
Contingency		0	(783)	318	(166)	184	45	(148)
TOTAL DIFFERENTIAL COST	Base	0	(4 698)	1 906	(1 000)	1 104	270	(890)

NOTES: 1) Items in brackets ( ) are negative.
2) All costs 3rd Quarter 1984 Canadian $.
3) All costs are relative to Alternative 1.

TABLE C-2

DIFFERENTIAL OPERATING AND MAINTENANCE COST ESTIMATE SUMMARY
($1000)

DESCRIPTION	ALTERNATIVE 1	2	3	4	5	6	7	8
Personnel	Base	0	(36)	(36)	0	0	0	(36)
Electric Power	Base	36	34	19	0	(32)	(43)	(35)
Water	Base	3	18	2	0	2	0	(2)
Fuel Gas	Base	(14)	797	92	0	0	0	46
Chemicals	Base	25	0	(132)	0	353	(175)	(405)
Residue Disposal	Base	100	(1 572)	(1 456)	(135)	482	(160)	(1 502)
Plant Maintenance	Base	30	(87)	41	40	44	(6)	51
TOTAL DIFFERENTIAL COST	Base	180	(846)	(1 470)	(175)	849	(384)	(1 883)

NOTES: 1) Items in brackets ( ) are negative.
2) All costs 3rd Quarter 1984 Canadian $.
3) All costs are relative to Alternative 1.

APPENDIX D

COST OPTIMIZATION OF SELECTED FLUE GAS TREATMENT SYSTEM

COST OPTIMIZATION OF SELECTED FLUE GAS TREATMENT SYSTEM

INTRODUCTION

The optimization of the selected flue gas treatment system is described in Section 4.3.4 (pg. 166). An optimum design for the flue gas treatment system can be selected based on performance, however, several designs offer the same performance. These different designs are compared in this appendix based on cost factors to select the final optimum design (pg. 181).

This Appendix D reflects work conducted by OWMC's Incineration Technology Consultants.

Basis and Methodology

In making the cost comparison between the different "optimum" system designs, the only variables which need to be considered are the actual differences between the systems. Therefore, equipment, maintenance and other costs common to all designs are neglected. As a result, the optimization basically becomes a comparison of capital cost versus operating cost. In this analysis, the operating costs are determined for the service life of the equipment and a present value for this series of costs is determined. This is then added to the installed cost of the equipment to determine which system has the lowest present value, and reflects the optimum design for the given conditions.

The cost factors used in this evaluation are as follows;

- o Equipment Service Life — 20 years
- o Cost of Capital — 11%
- o Escalation Rate — 7% per year
- o Operating Hours — 7 000 hours per year
- o Electricity Cost
  - Usage Charge — 1.69 cents per kilowatt-hour
  - Demand Charge — $4.30 per installed kilowatt

Note: Differences between these economic factors and those included in Appendix C, or other OWMC reports, reflects changes agreed with OWMC at different stages of the Facilities Development Process.

Cost Comparison

Present value of operating costs for different scrubber Ring Jet™ pressure drops are as follows:

Ring Jet™ Pressure Drop	Additional Fan Horsepower	Additional First Year Cost	Present Value
250 mm WG	--	--	--
400 mm WG	110 Hp	$13 950	$181 630
600 mm WG	180 Hp	$22 850	$297 500

Capital costs for electrostatic precipitators having different efficiencies are as follows:

Capital Costs

Precipitator Efficiency	Additional Cost
98%	--
99%	$ 80 000
99.9%	$310 000

Combined costs for flue gas treatment systems having different Ring Jet™ pressure drops and different electrostatic precipitator efficiencies, but all having the same overall performance are as follows:

Optimized Systems Present Value Costs

Precipitator Efficiency	Ring Jet ™ Pressure Drop	Present Value Additional Cost
98%	600 mm WG	$ 297 500
99%	400 mm WG	$ 261 600
99.9%	250 mm WG	$ 310 000

From this analysis, it is evident that the optimum design from a cost viewpoint is the one in the middle, having an electrostatic precipitator efficiency of 99% and a Ring Jet™ pressure drop of 400 mm WG.